UAS Modeling of the Communication Links Study Results

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UAS Modeling of the Communication Links
Study Results
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UAS Fast-Time Control and Communication Modeling and Simulation

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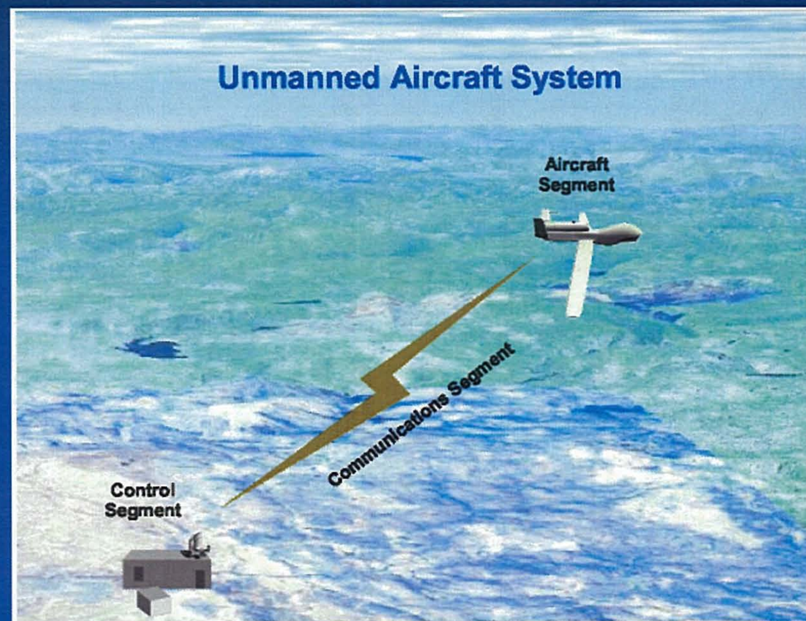
Introduction

Overview of Unmanned Aircraft Systems and Types

- 2.2 UAS
- 2.2.1 Aircraft Segment
- 2.2.2 Control Segment
- 2.2.3 Communication Segment
- 2.3 Support Element
- 2.4 UAS Types
- 2.5 System Architectures

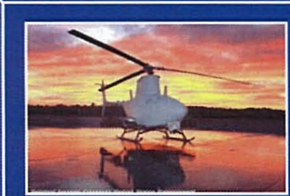


Overview of Unmanned Aircraft Systems and Types

- 2.2 UAS

- Aircraft Segment
- Control Segment
- Communications Segment

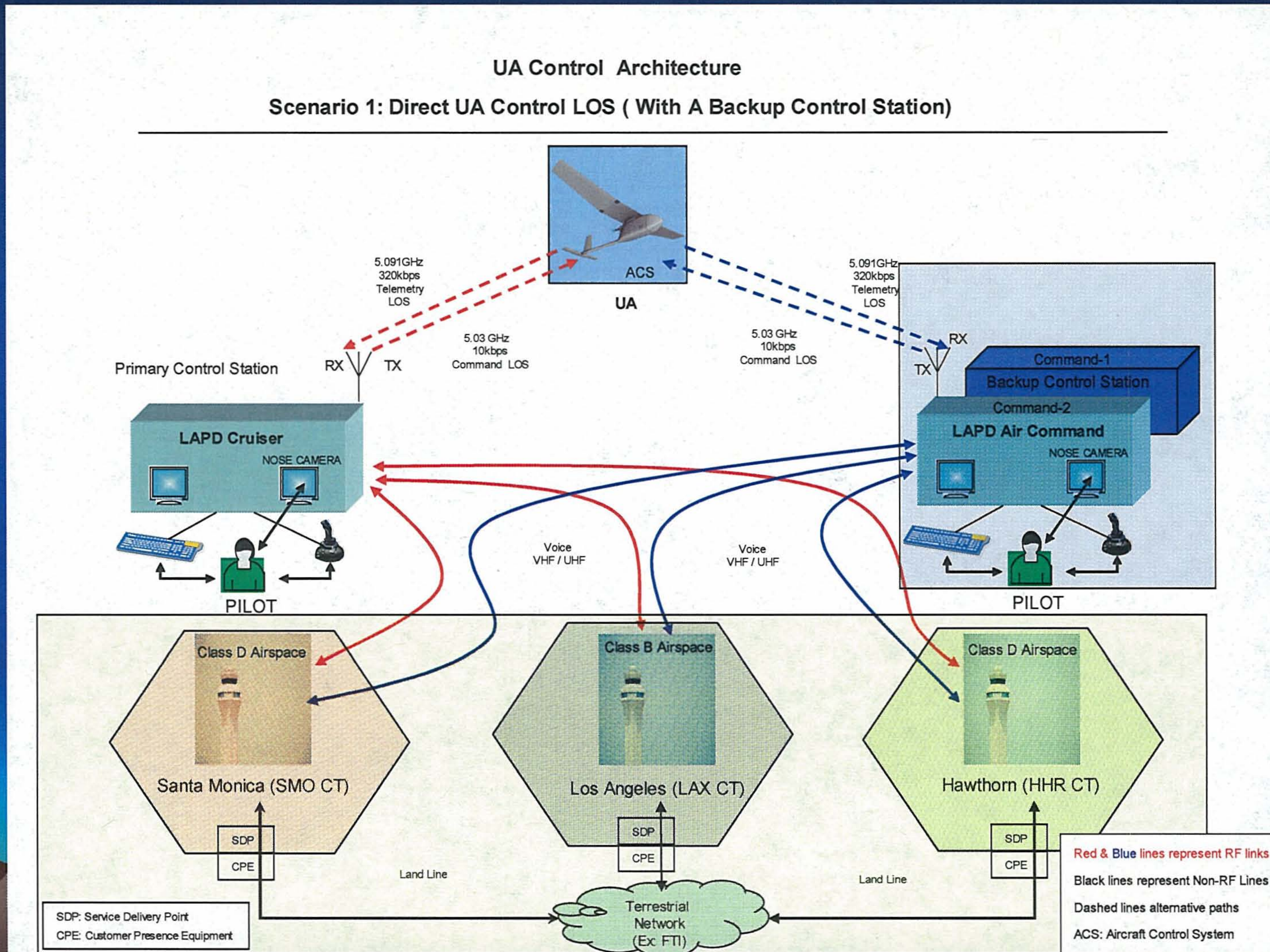
- This report encompasses modeling the communication links between these three segments – namely - modeling the Control link to the UAS as well as the telemetry link from the aircraft.



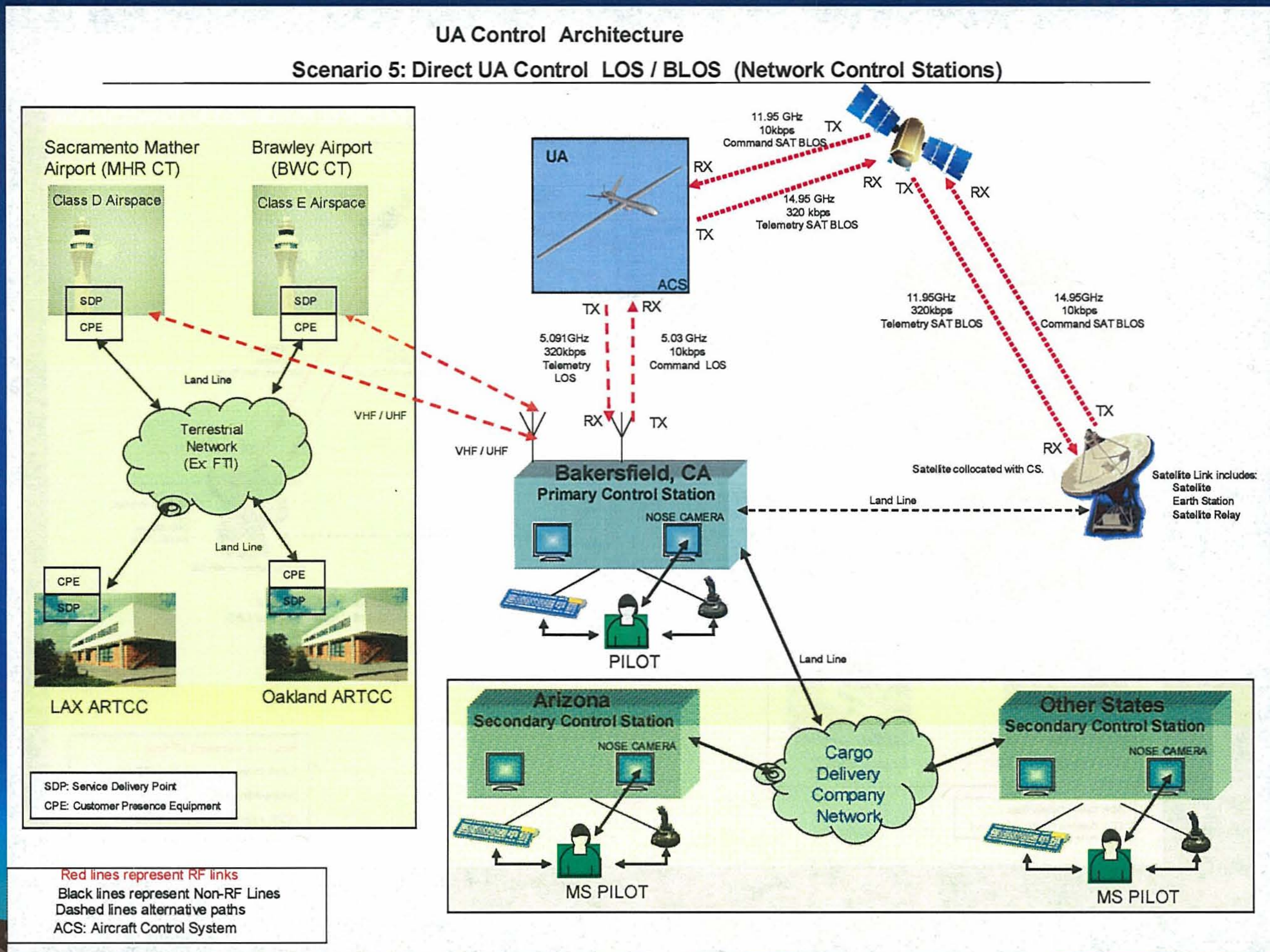
Description of Modeled Architectures

- 3.1 Direct Control Architectures LOS / BLOS
- 3.2 Nationwide Network Control
- 3.3 Scenarios
- 3.3.1 Scenario 1 - LOS Control
- 3.3.2 Scenario 5 - LOS / BLOS Control
- 3.3.3 Scenario 6 - LOS / BLOS Control

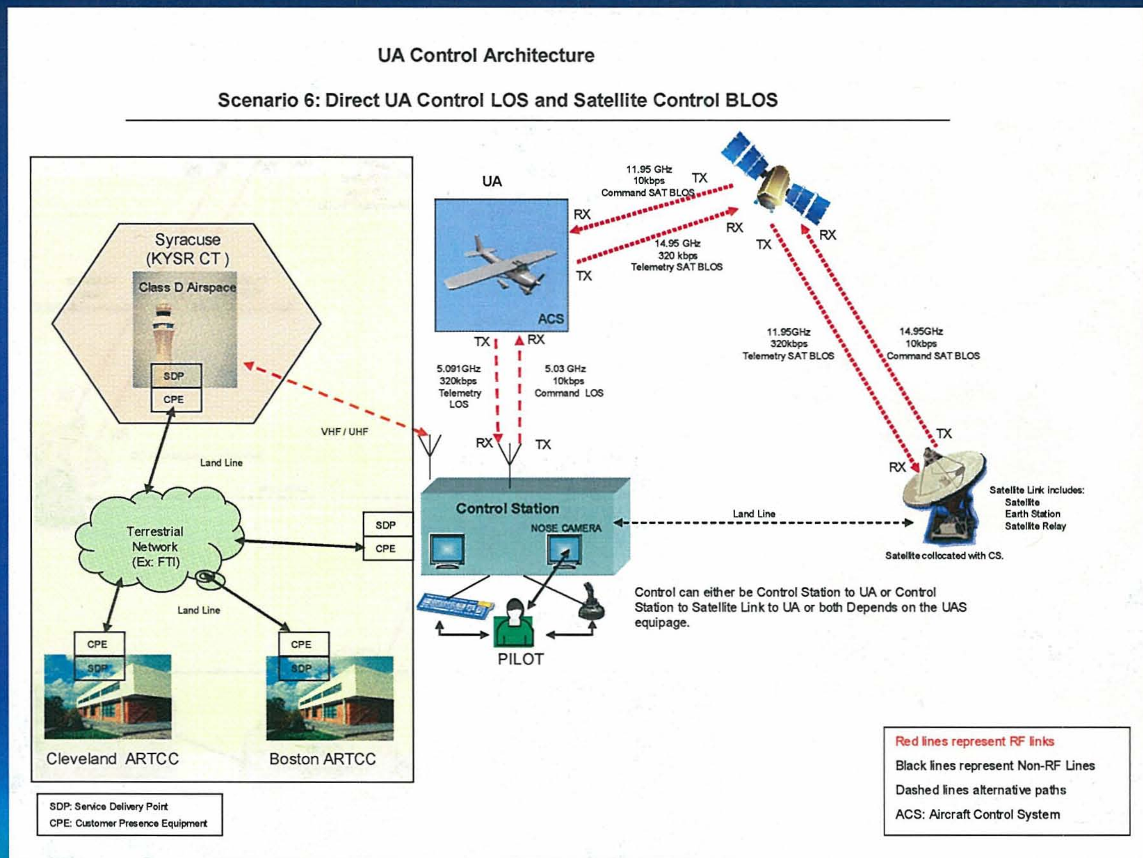
UA Control Architecture



LOS/BOS Network Control



Direct UA Control LOS/BLOS



Operational Concept

- This report primarily focuses on modeling the UAS Control architectures associated with control and telemetry communication links between CSs, UA, and satellites within the NAS.
- 4.1 Communications Systems
- 4.1.1 Telecommunications
- 4.1.2 Mobile Communications
- 4.1.3 Satellite Communications
- 4.1.4 Voice Communications

Operational Concepts

- 4.1 Communications Systems
- The communication system modeled encompasses:
- Command Links
  - LOS: This is a 10 kbps link using quadrature phase shift key (QPSK).
    - Two receive antennas on the UAS, top and bottom, configured in the middle of the plane. These are half hemispherical antennas
    - One Transmit antenna, directional to the UAS from the ground
  - BLOS
    - One UAS Directional Antenna up to A GEO Satellite
    - One Directional Receive Antenna on the GEO
    - One Directional Transmit Antenna on the GEO down to the Vehicle
    - One Receive antenna on the UAS, top, configured in the middle of the plane. These are half hemispherical antennas
- Telemetry Links: This is a 320 kbps link using QPSK. This link uses the same antenna configuration as command but at different frequencies. The frequencies, power and other link information is discussed in sub-sections of link budgets section 6.5.

Operational Concepts

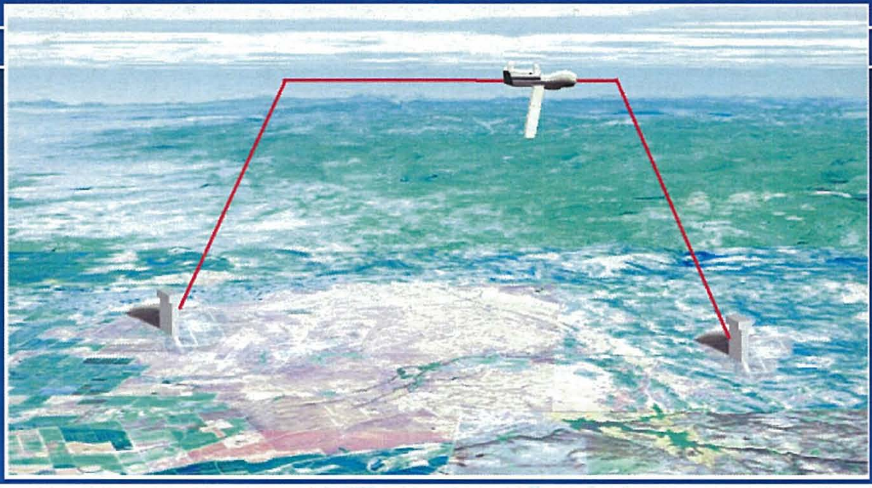
- 4.1.1 Telecommunications
- This section requires future studies and will require in-depth investigation. Fast-Time modeling and analysis will address current infrastructure, FTI networks and future NextGen concepts specific to UAS voice, data, and video.

- 4.1.2 Mobile Communications
  - Scenario 1 provides an example a stationary unit with a LAPD Cruiser using mobile communications to control and receive telemetry between the UA, communicate to ATC and to a backup control center.

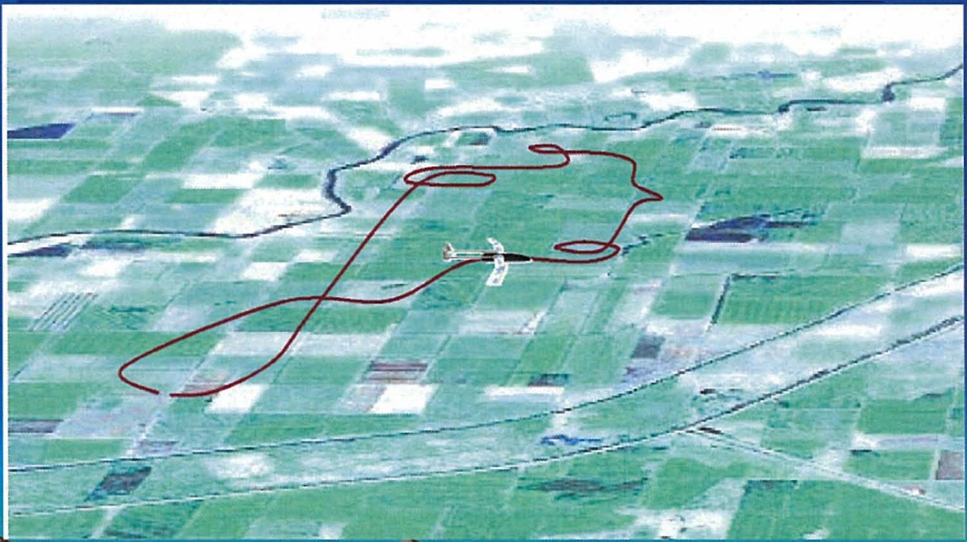
- 4.1.3 Satellite Communications
  - RF links between the satellite and satellite earth station
  - Satellite relay link between the CS and satellite

- 4.1.4 Voice Communications
  - Additional studies will address ATC to UAS voice communications and other entities like Air Route Traffic Control Centers (ARTCC).

Flight Profiles

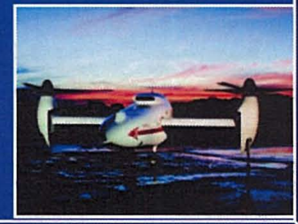


- 5.1 Point-to-Point
- 5.2 Planned Aerial Work
- 5.3 Unplanned Aerial Work



Modeling and Simulation

Modeling and Simulation

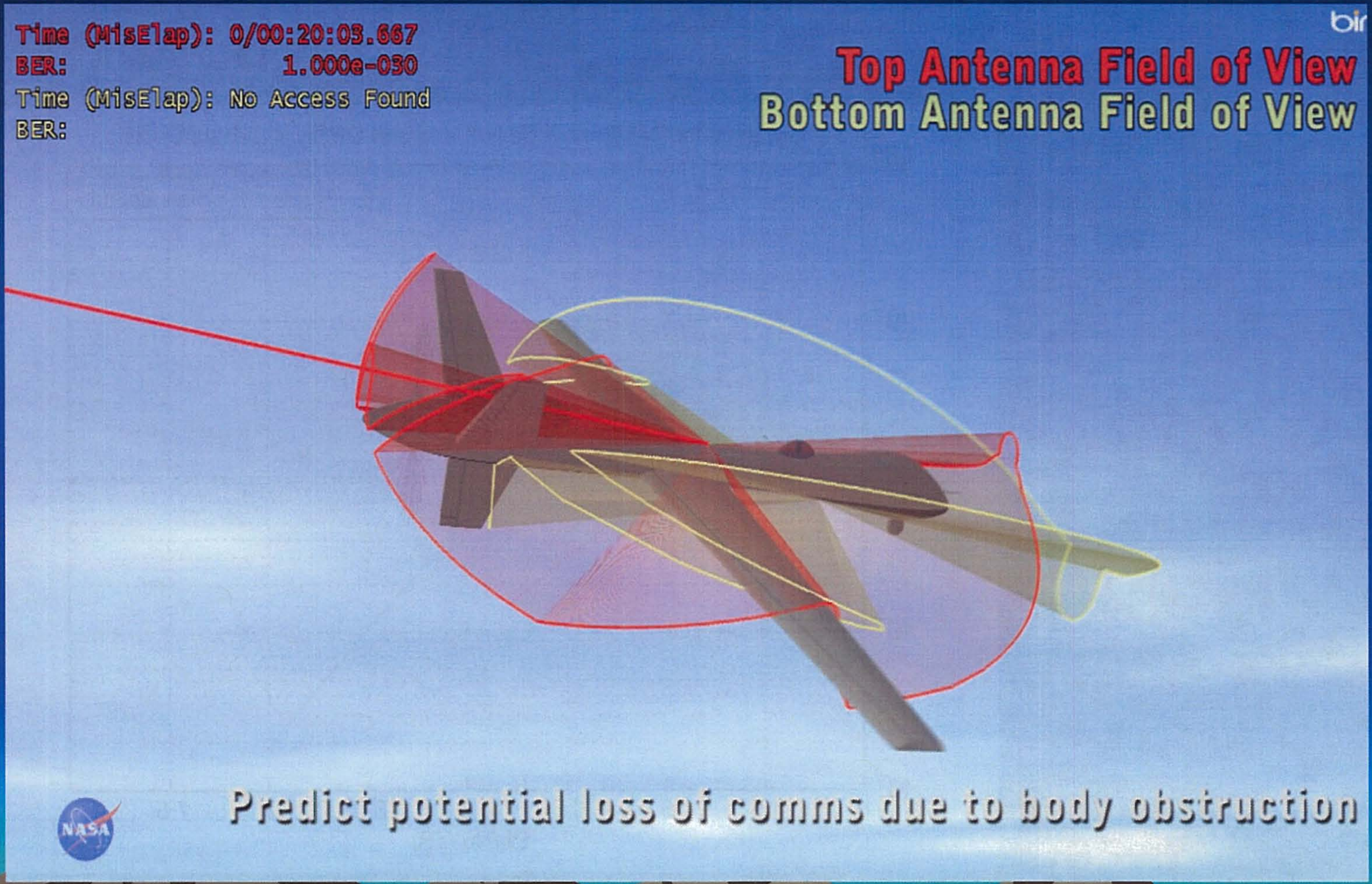


- 6.1 Approach

- The FAA and NASA KSC Modeling and Simulation (M&S) approach was to develop all RTCA SC-203 Operational Services and Environmental Definitions (OSED) scenarios for communications link modeling utilizing a common environment -- the Analytical Graphics, Inc. (AGI) Satellite Tool Kit (STK) application.
- Additional, the Scalable Networks Technologies product, QualNet, was used as an interface with STK.
- Nine Scenarios were modeled with STK's Mission Modeler.
- After meeting with RTCA SC203

  Three scenarios were modeled for in-depth analysis of the communication systems.
- The Aircraft Mission Modeler propagator for the aircraft object is a premier tool for performing complex, highly accurate, time-based mission analysis for aircraft operations.
  - All scenarios used the same Aircraft model
- Antennas placed on any UAS will be blocked due to the masking of the aircraft body on the antenna pattern.

Antenna Mask

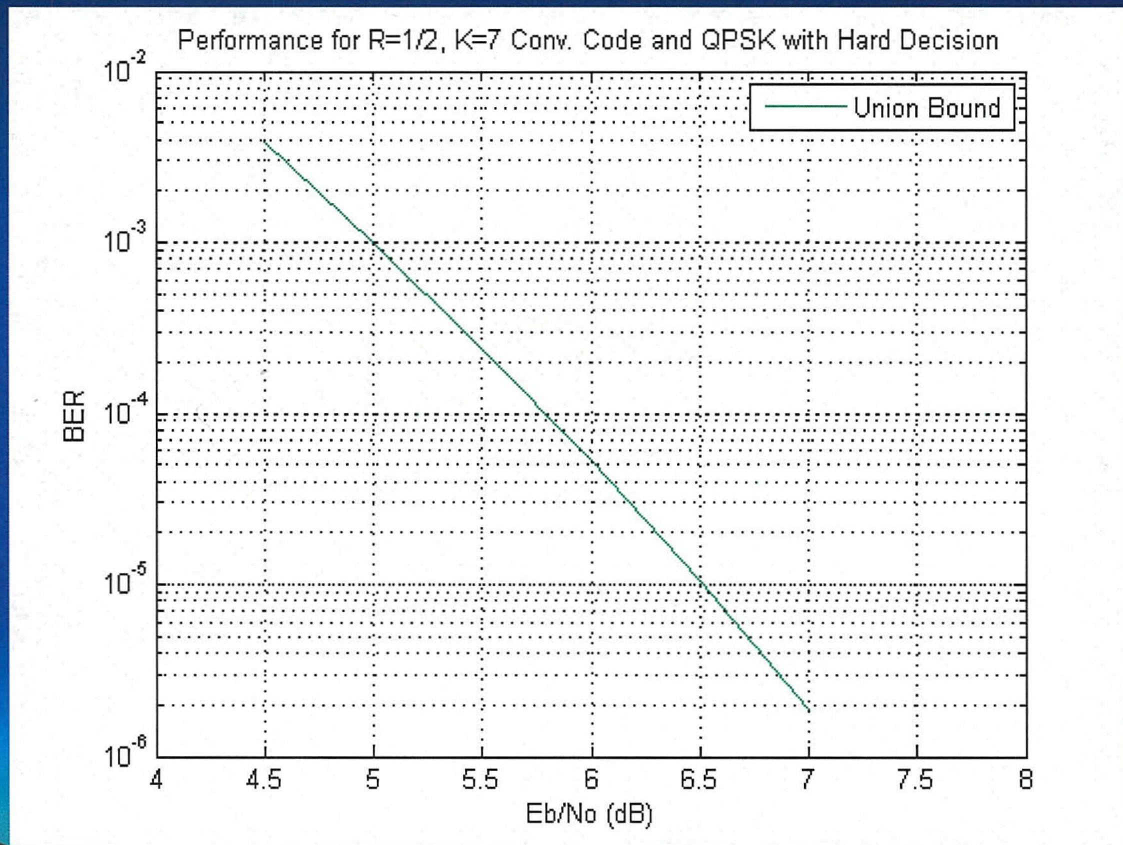


Link Budgets

6.5 Radio Link Budget

The LOS Link Margin(**Table 2**) is calculated for a 25 Nautical Mile (NM) range. This is in direct comparison of the results reported in RTCA document on availability which uses the calculations for 25 NM.

This simulation used 6.5 dB Eb/No and a 10 minus 5th BER



Link Margin

- The result of the link analysis below shows a total excess margin of 18.5 dB Margin for ground to UA and 6.5 dB for UA to ground.

	Command	Telemetry
	Ground to UA	UA to Ground
Transmit Power (dBm)	30	32
Transmit Antenna Gain (dB)	28	-10
Transmit Cable Loss (dB)	-2	-2
Transmit EIRP	56	20
Path Loss (dB) (5 GHz, 25 NM)	-138	-138
Atmospheric Loss Margin (dB)	0	0
Multipath Loss Margin (dB)	-20	-20
Receiver Antenna Gain (dB)	-10	28
Receiver Cable Loss (dB)	-2	-2
Received Signal Power (dBm)	-94	-92
Thermal Noise @290 K	-174	-174
Receiver NF (dB)	2	2
Receiver BW (dBHz) (20khz &320Khz)	43	55
Receiver Noise Power (dBm)	-129	-117
Carrier-to-Noise Ratio (C/N)(dB)	35	23
Implemented Loss Margin	-4	-4
Safety Margin (dB0	6	6
Required C/N (dB) with Convolution Code	12.5	12.5
Excess Margin (dB)	18.5	6.5

LINK MARGIN

- The Table shows the link budget for the BLOS links. The BLOS link is different than the LOS link since it has two hops for each of the links, command and telemetry, which are: CS to Satellite, Satellite to UA for command, and then the reverse path for telemetry.
- As to be expected the link from the Ground station, with a large antenna, is more robust than the link from the satellite to the UA. The excess margin is 21.2 dB for the ground to satellite and a -0.65 dB excess margin for satellite to UA. This -0.65 dB would barely lower the BER of 10-5.

	Command 14 GHz	Command 11GHz
	Ground to Satellite	Satellite to UA
Transmit Power (dBm)	21.5	9.2
Transmit Antenna Gain (dB)	59.1	38.2
Transmit Cable Loss (dB)	-2.14	-3.86
Transmit EIRP	78.46	43.54
Path Loss (dB) (5 GHz, 25 NM)	-208.46	-207.17
Atmospheric Loss Margin (dB) Rain	0	0
Receiver Antenna Gain (dB)	39.3	40.08
Receiver Cable Loss (dB)	-1	-0.5
Received Signal Power (dBm)	-91.7	-124.05
Thermal Noise @290 K	-174	-174
Receiver NF (dB)	11.6	1.1
Receiver BW (dBHz) (20khz &320Khz)	43	43
Receiver Noise Power (dBm)	-119.4	-129.9
Carrier-to-Noise Ratio (C/N)(dB)	27.7	5.85
Implemented Loss Margin	0	0
Required C/N (dB) with Convolution Code	6.5	6.5
Excess Margin (dB)	21.2	-0.65

Link Margin

Tab

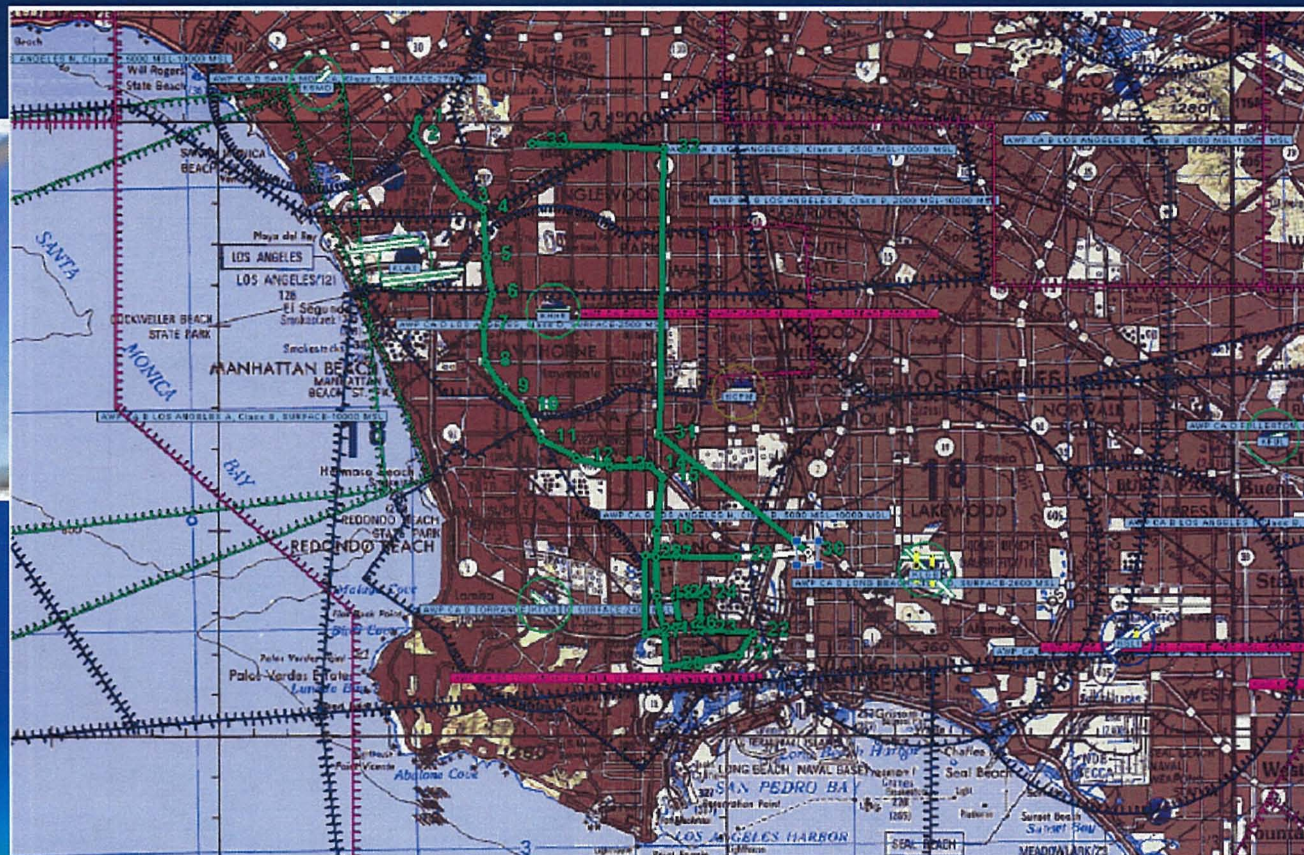
This Table shows the link margin for the telemetry link of BLOS. The excess margin is 11.88 dB for the UA to Satellite and 15.14 dB for the Satellite to CS.

	Telemetry 14GHz	Telemetry 11GHz
	UA to Satellite	Satellite to CS
Transmit Power (dBm)	38.9	17.62
Transmit Antenna Gain (dB)	39.67	38.2
Transmit Cable Loss (dB)	-4.17	-2.17
Transmit EIRP	74.4	53.65
Path Loss (dB) (5 GHz, 25 NM)	-209.55	-206.51
Atmospheric Loss Margin (dB) Rain	0	0
Receiver Antenna Gain (dB)	39.7	57.6
Receiver Cable Loss (dB)	-4.17	-1
Received Signal Power (dBm)	-99.62	-96.26
Thermal Noise @290 K	-174	-174
Receiver NF (dB)	1	1.1
Receiver BW (dBHz) (20khz &320Khz)	55	55
Receiver Noise Power (dBm)	-118	-117.9
Carrier-to-Noise Ratio (C/N)(dB)	18.38	21.64
Implemented Loss Margin	0	0
Required C/N (dB) with Convolution Code	6.5	6.5
Excess Margin (dB)	11.88	15.14

Representative Scenarios

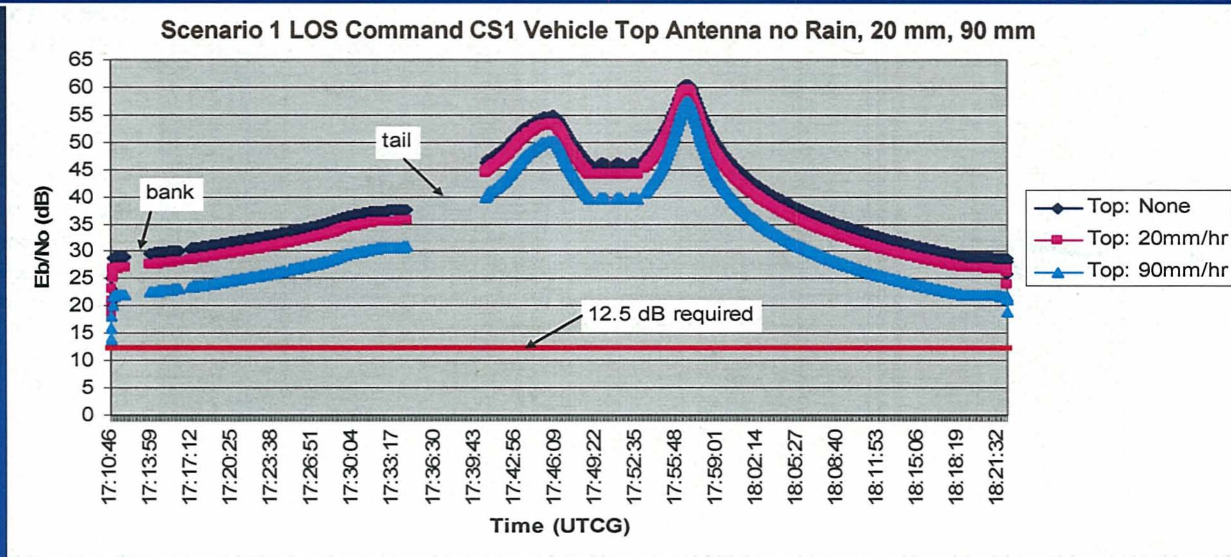
- Scenario 1 Law Enforcement
- Scenario 5 Cargo Delivery Turboprop Conversion
- Scenario 6 Border Surveillance and Tracking Turboprop

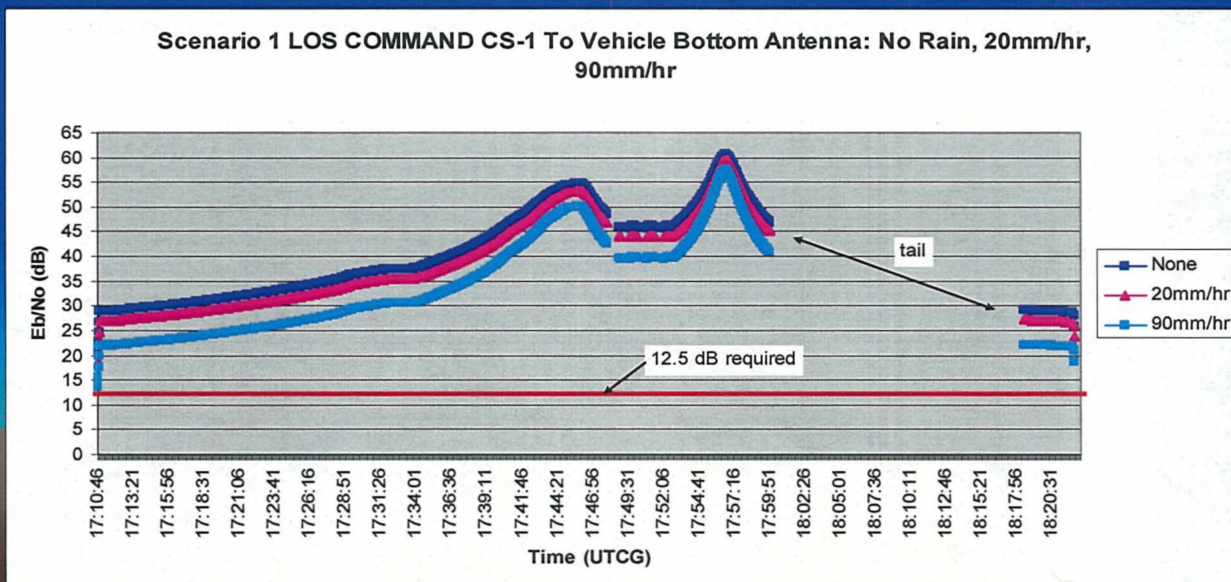
Scenario 1 Flight Overview



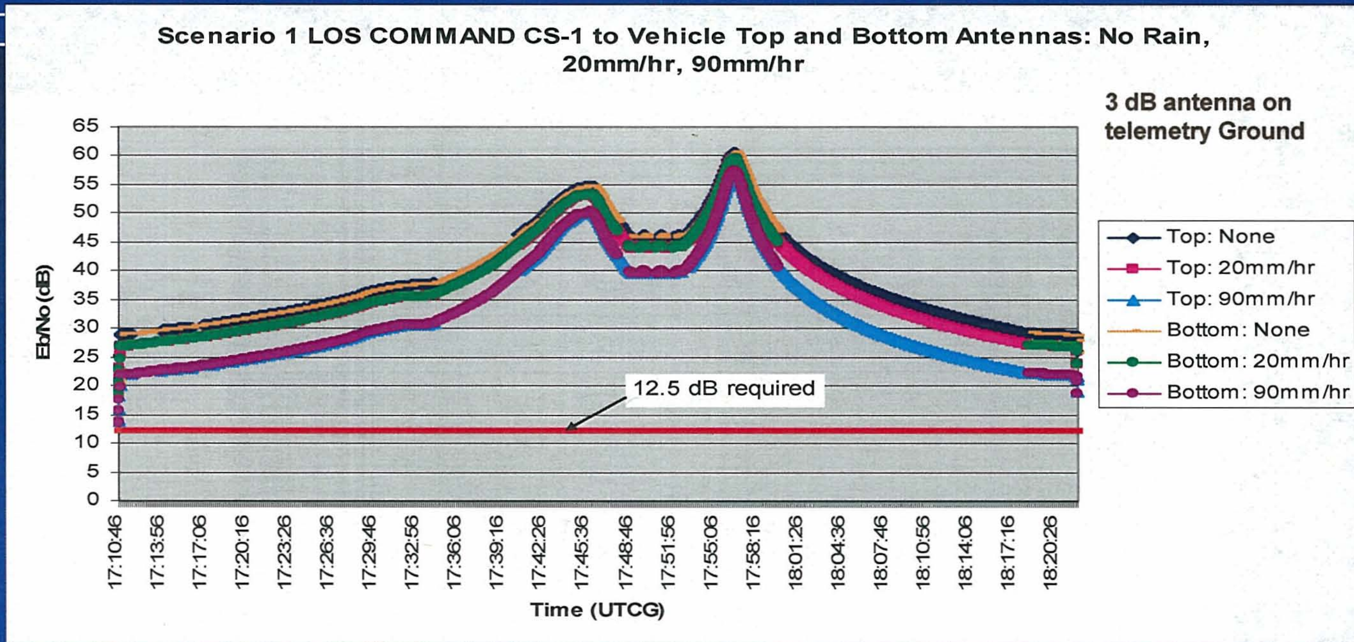
3-CS Locations

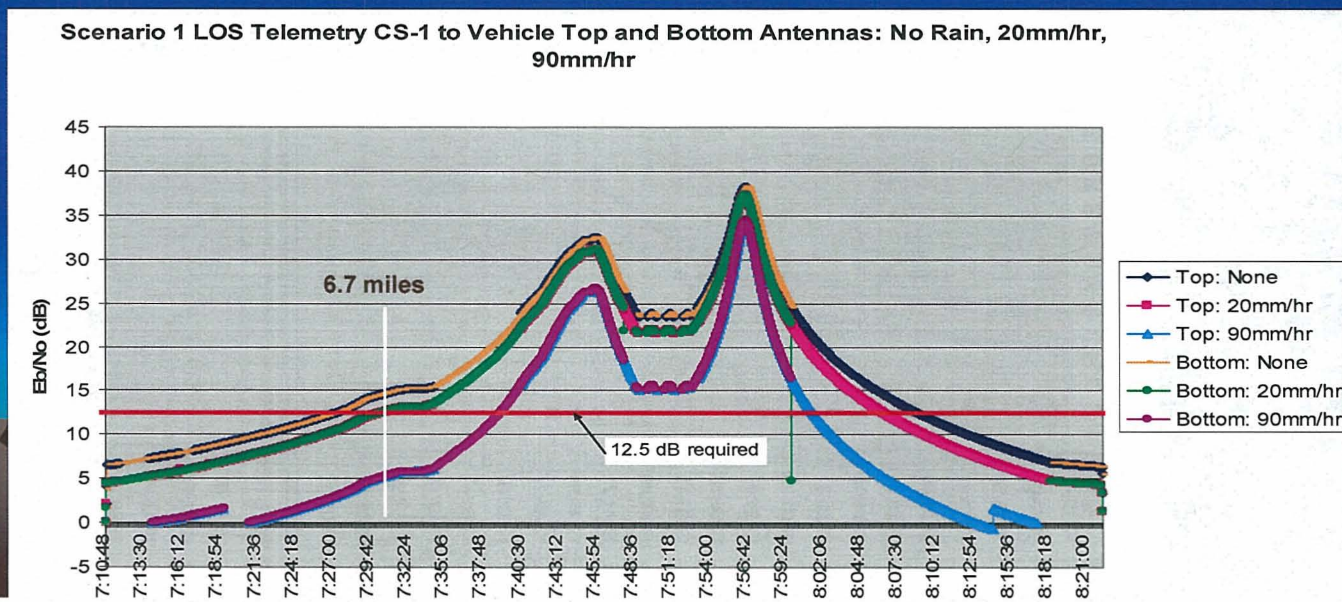
Scenario 1 Command Center 1





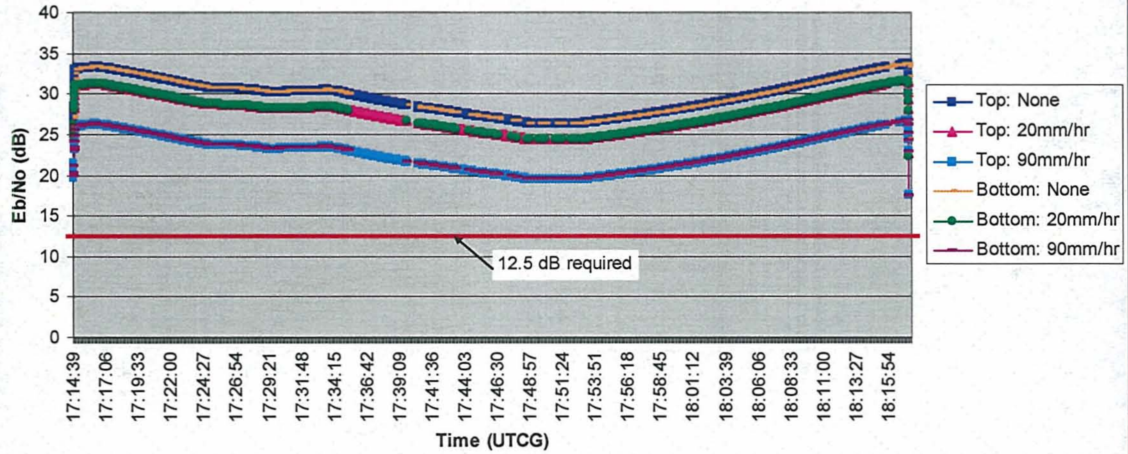
Scenario 1 Command Center 1



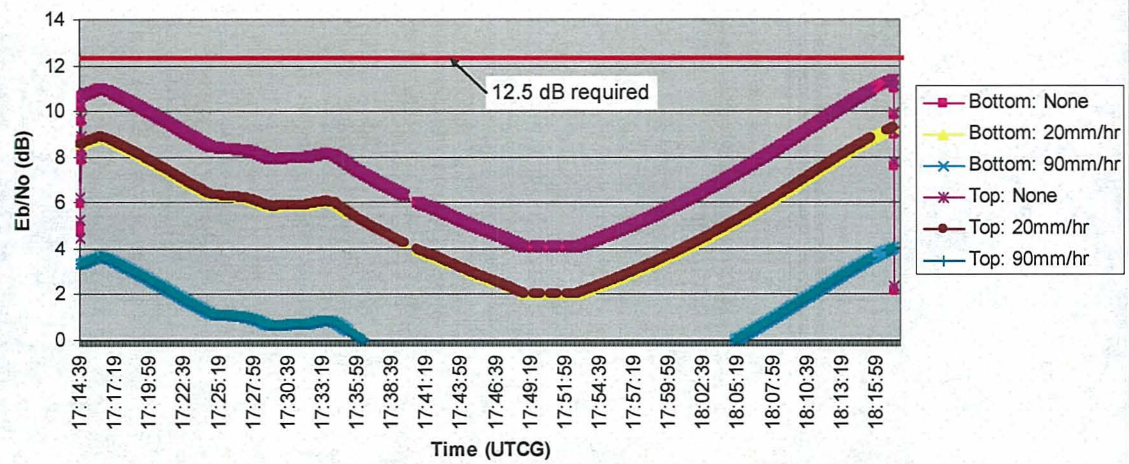


Scenario 1 Command Center 2

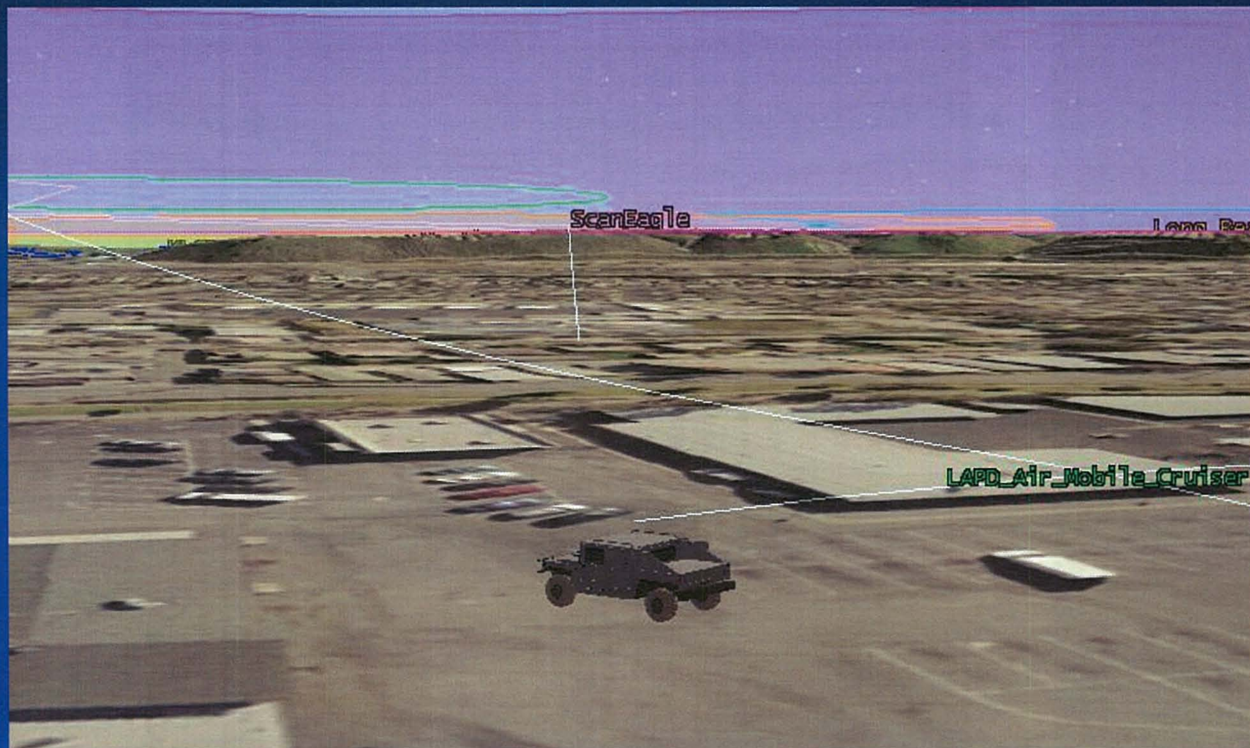
20mm/hr, 90mm/hr



Scenario 1 LOS Telemetry CS-2 to Vehicle Top and Bottom Antennas: No Rain, 20mm/hr, 90mm/hr

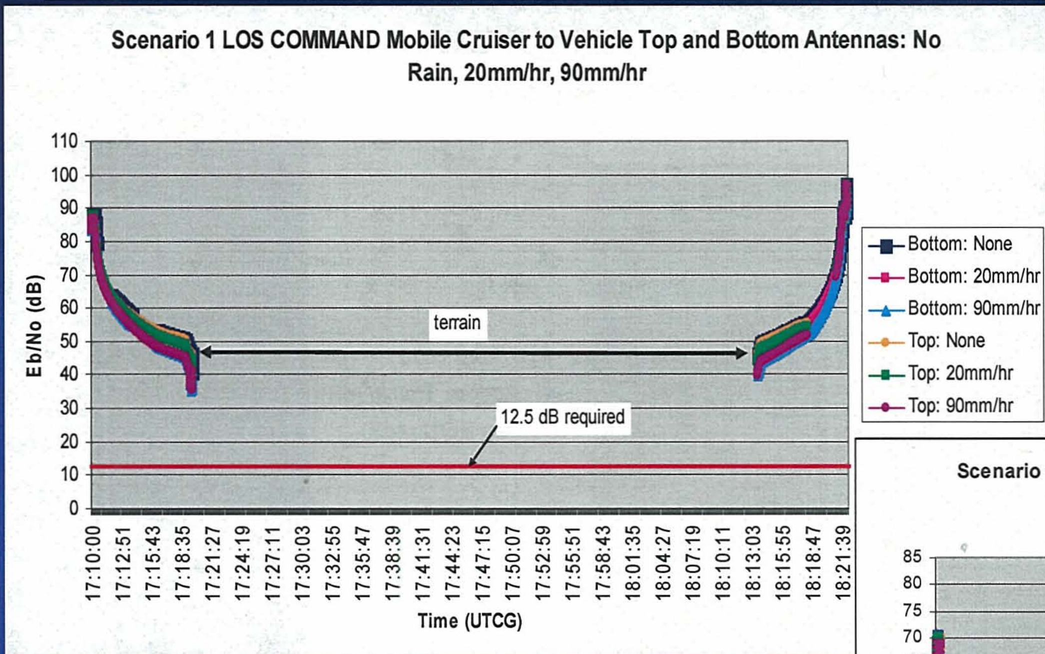


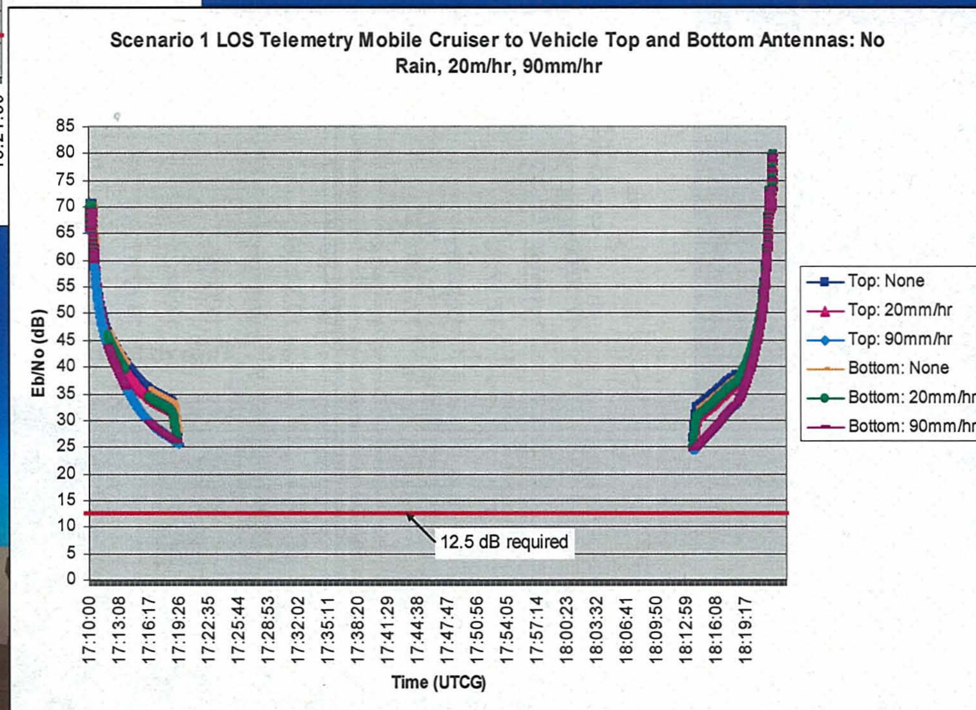
Scenario 1 Terrain Blockage



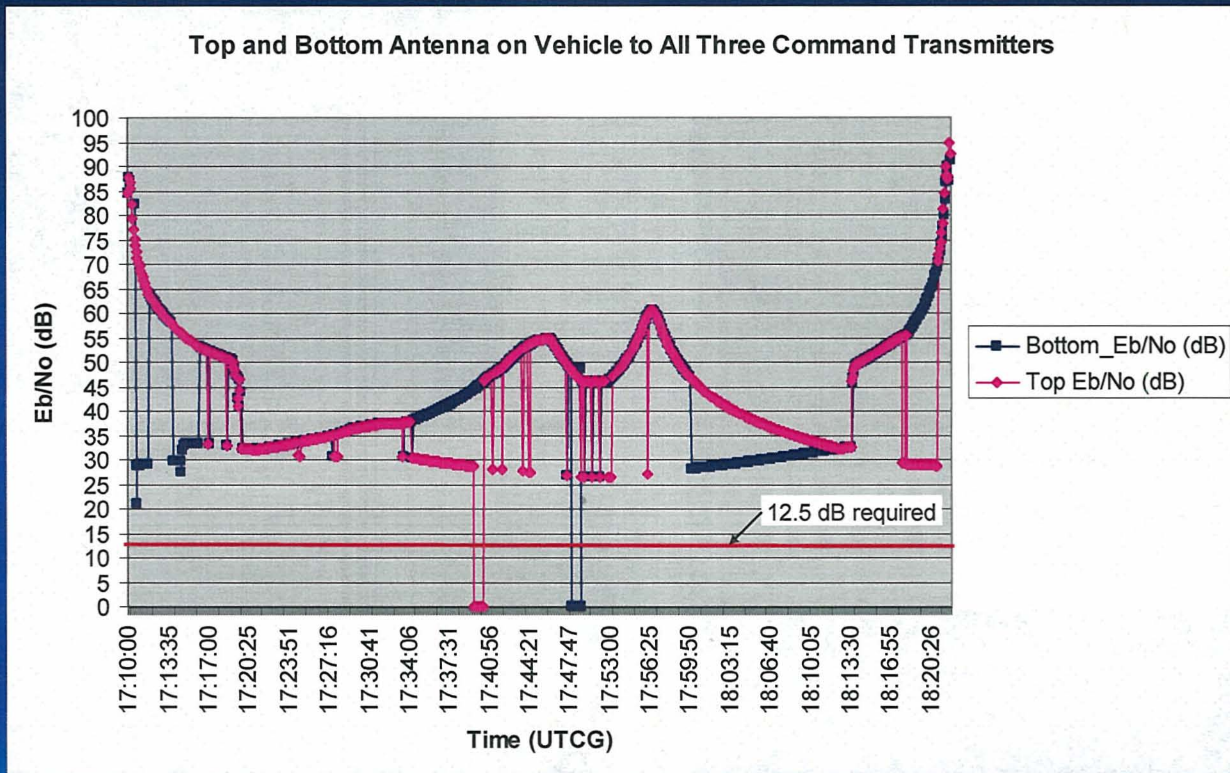
Land Mobile Cruiser Showing Terrain Blockage

Scenario 1 Mobile Cruiser





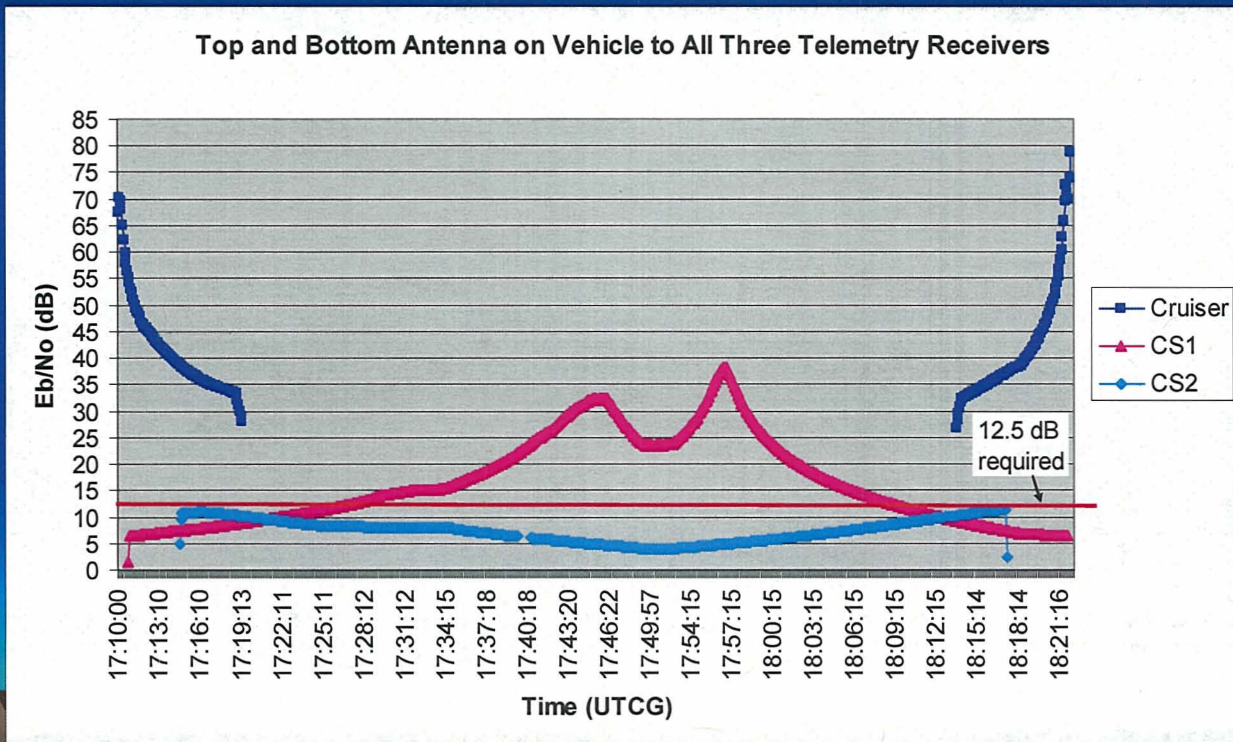
Scenario 1 All 3 CS



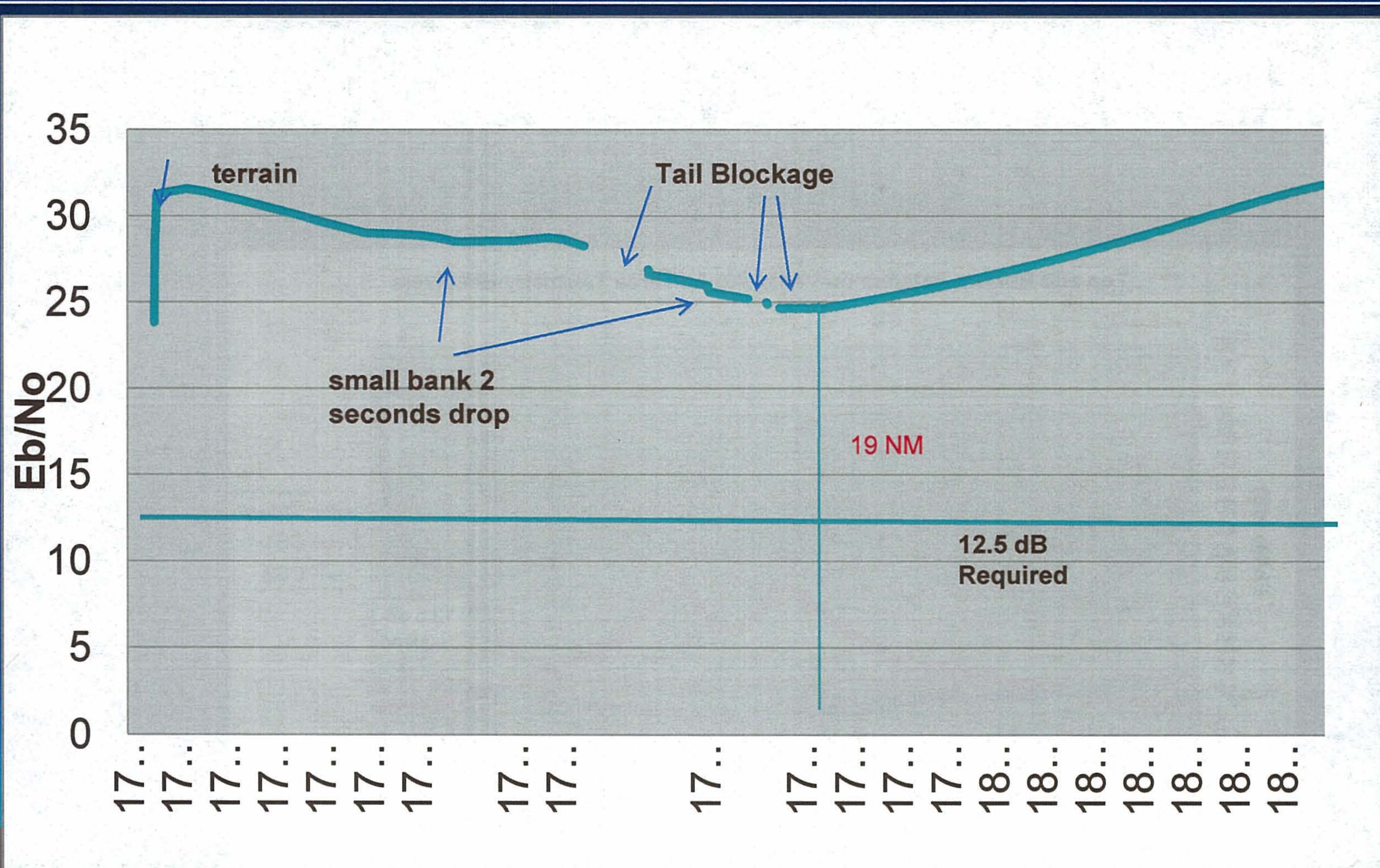
Scenario 1 Top and Bottom Antennas on Vehicle to All Three Command Transmitters

Combined Telemetry CS1

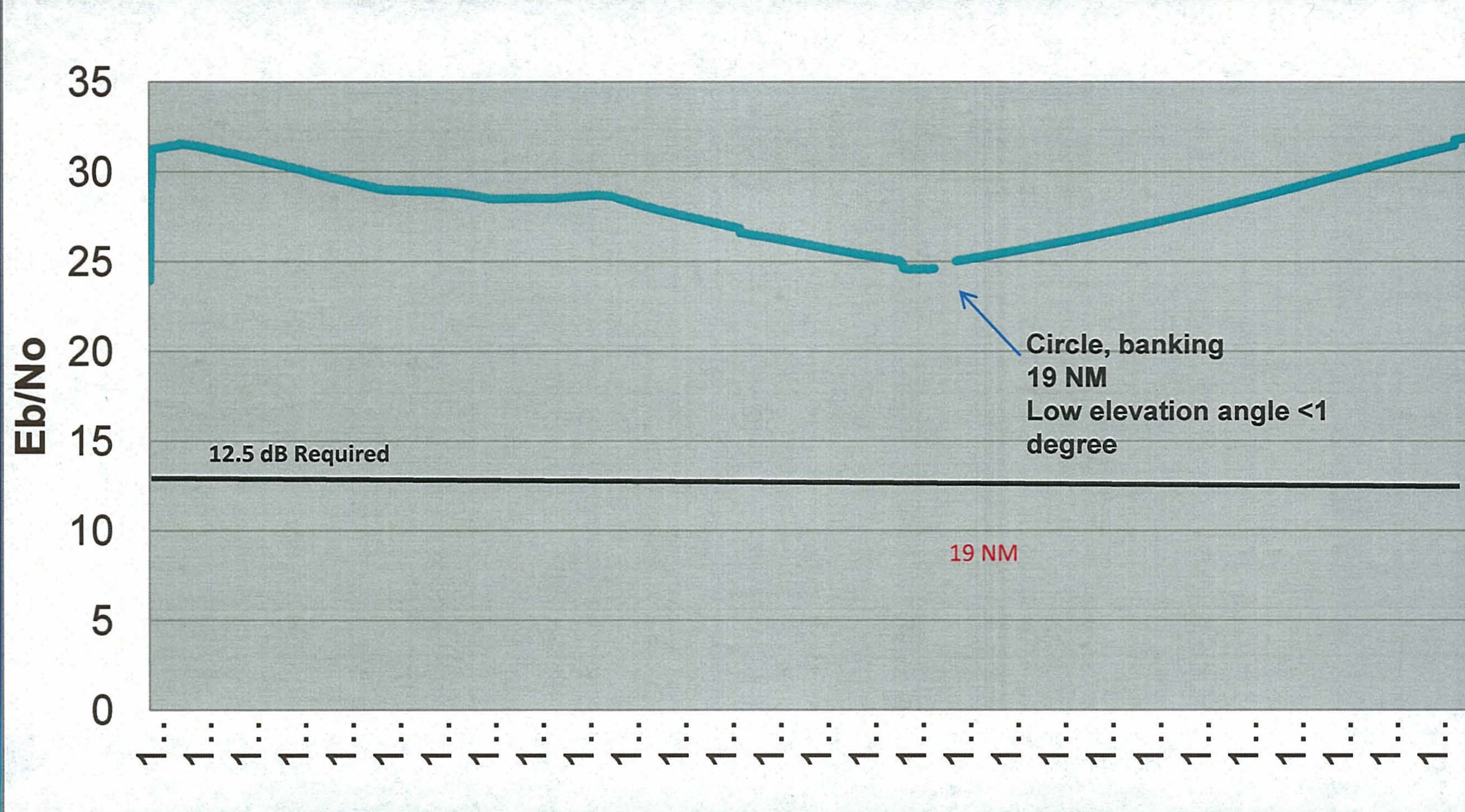
The figure below is the combined for all three CS for telemetry links. Here the results were not as good. The link is above the 12.5 dB required for most of the scenario. However about 17:19 the link drops down to 10 dB and does not go above 12.5 dB until 17:25 and then at the end of the scenario drops below 12.5 dB at 18:10 and picks up at 18:13. This was primary due to the closer range of the Mobile Cruiser compared to CS1 and CS2 thus showing a higher signal strength. CS2 is the furthest CS from the UA showing the smallest signal strength. If the criteria of 6.5 dB is used for the 10-5 BER the link holds up throughout the scenario.



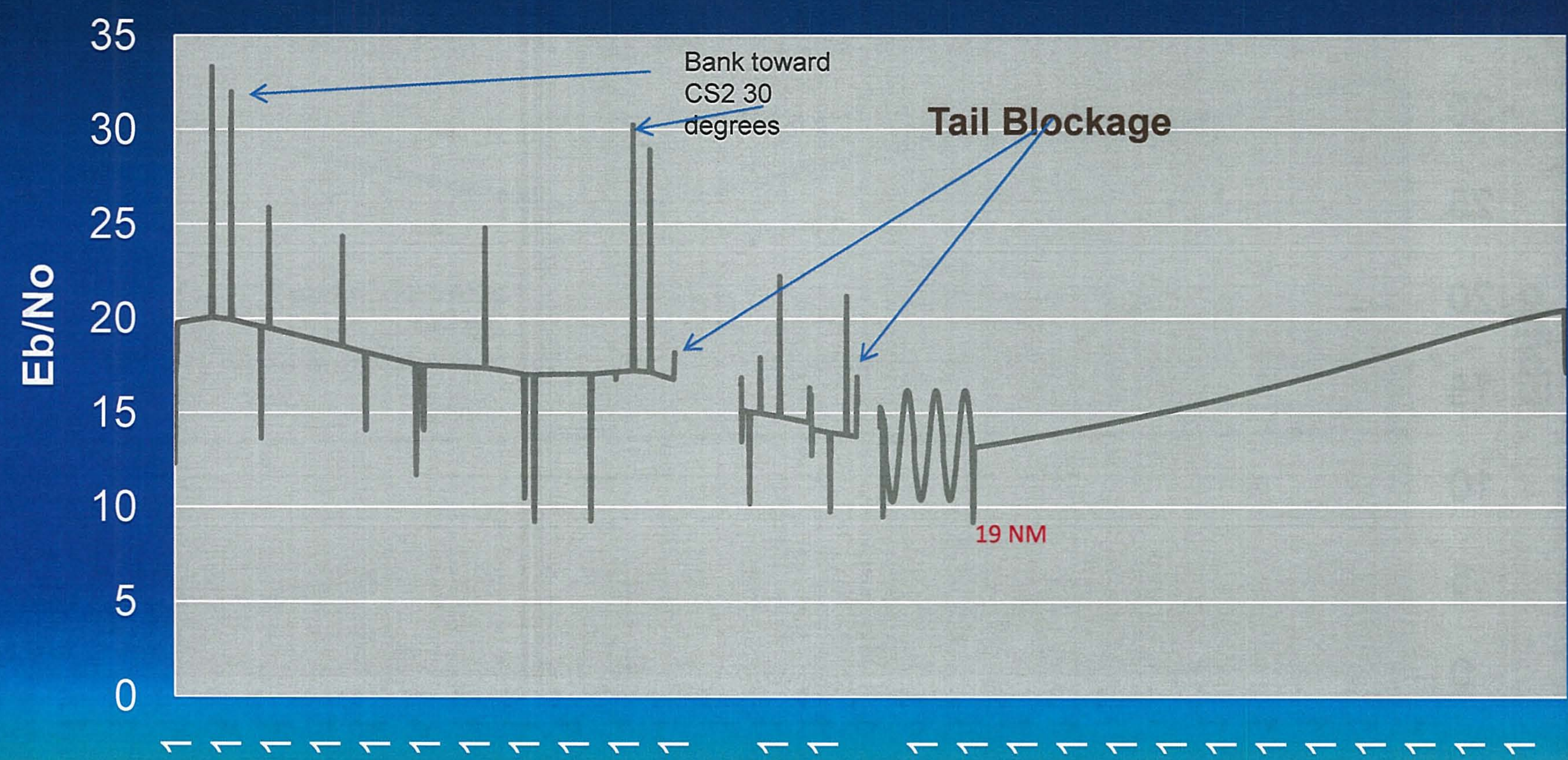
Telemetry 3 dB Hemispherical Bottom UA Antenna to CS2 28 dB Directional Antenna



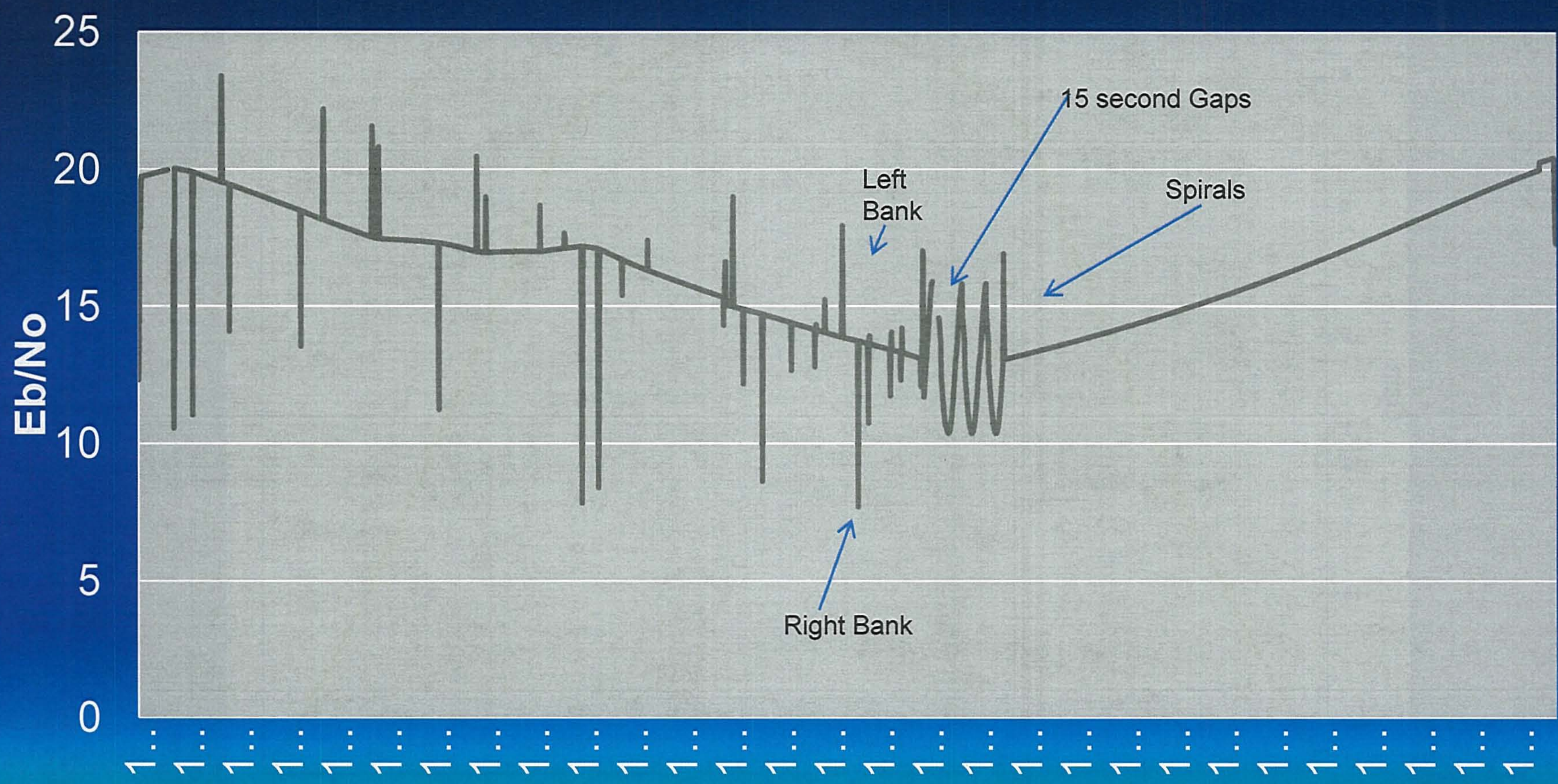
Telemetry 3 dB Hemispherical Top UA Antenna to CS2 28 dB Directional Antenna



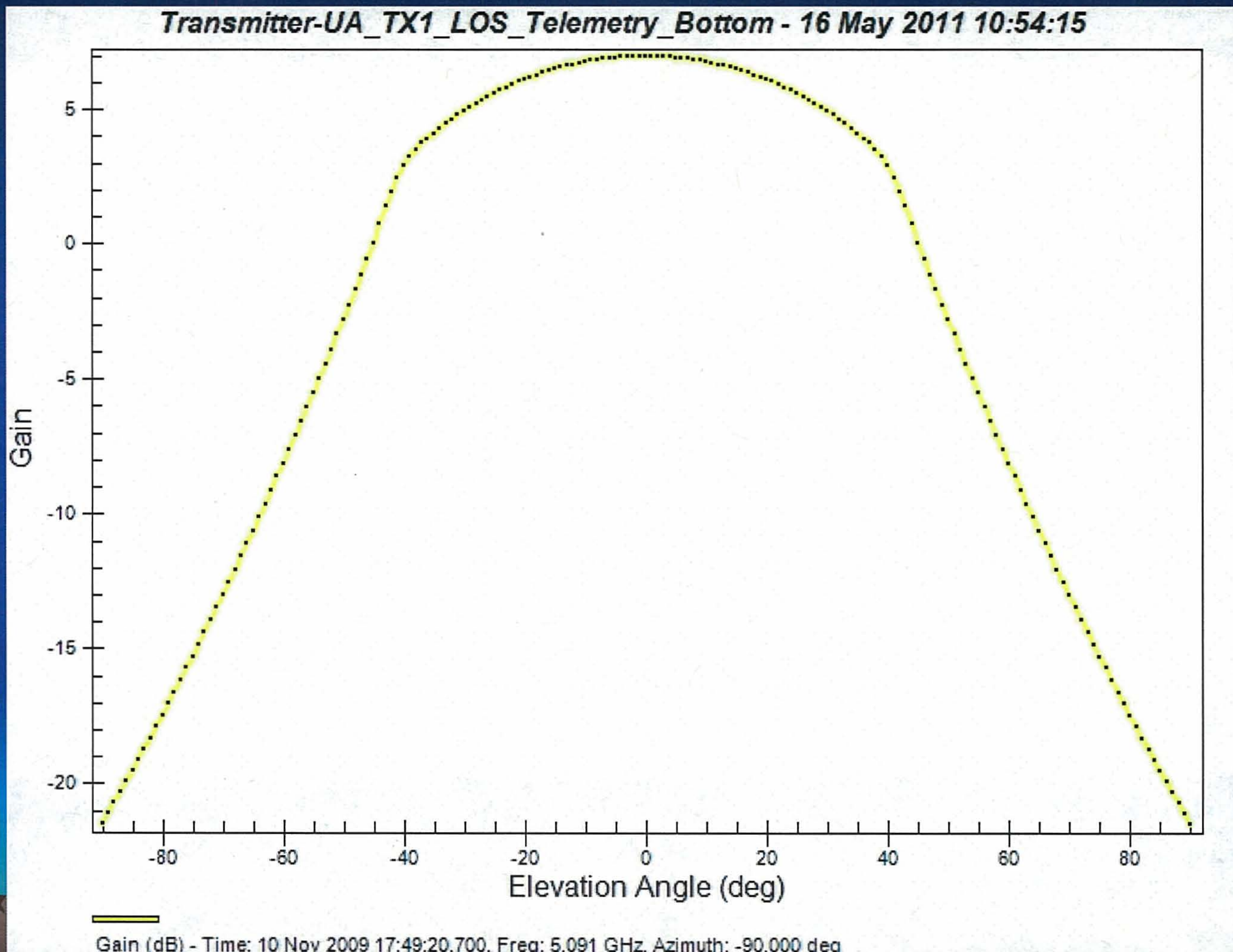
Telemetry UA Lemniscates Bottom UA Antenna to CS2 28 dB Directional Antenna



Telemetry UA Lemniscates Top UA Antenna to CS2 28 dB Directional Antenna



Lemniscates Top UA Antenna Pattern

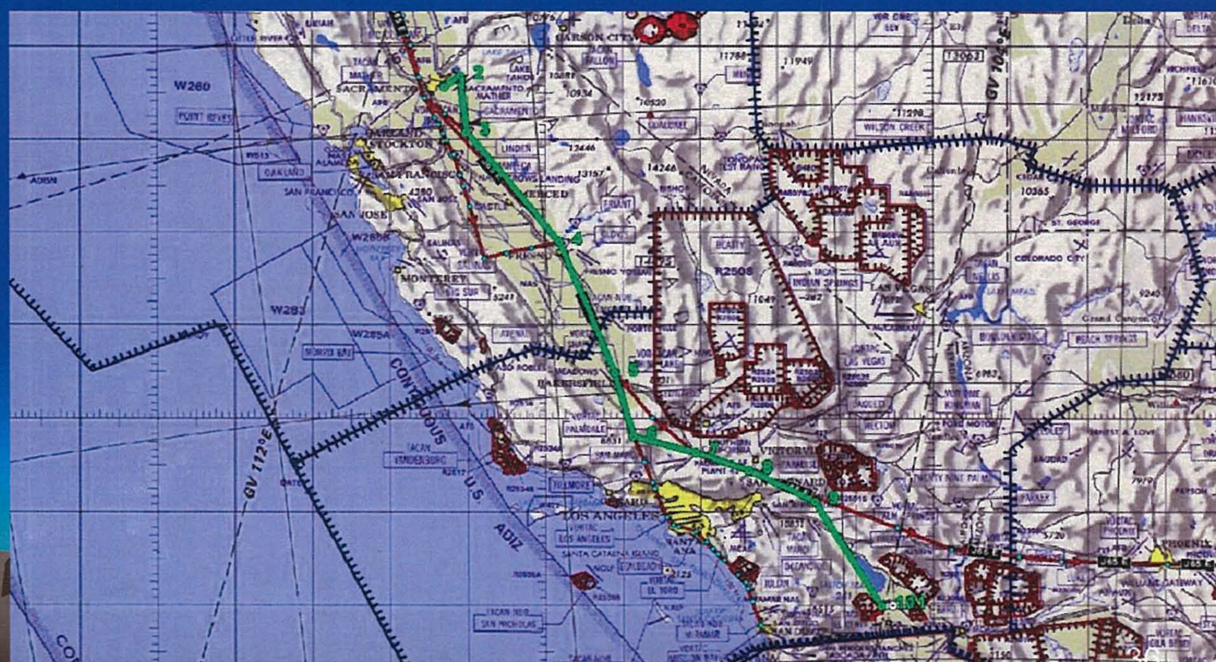


Scenario 1 Results

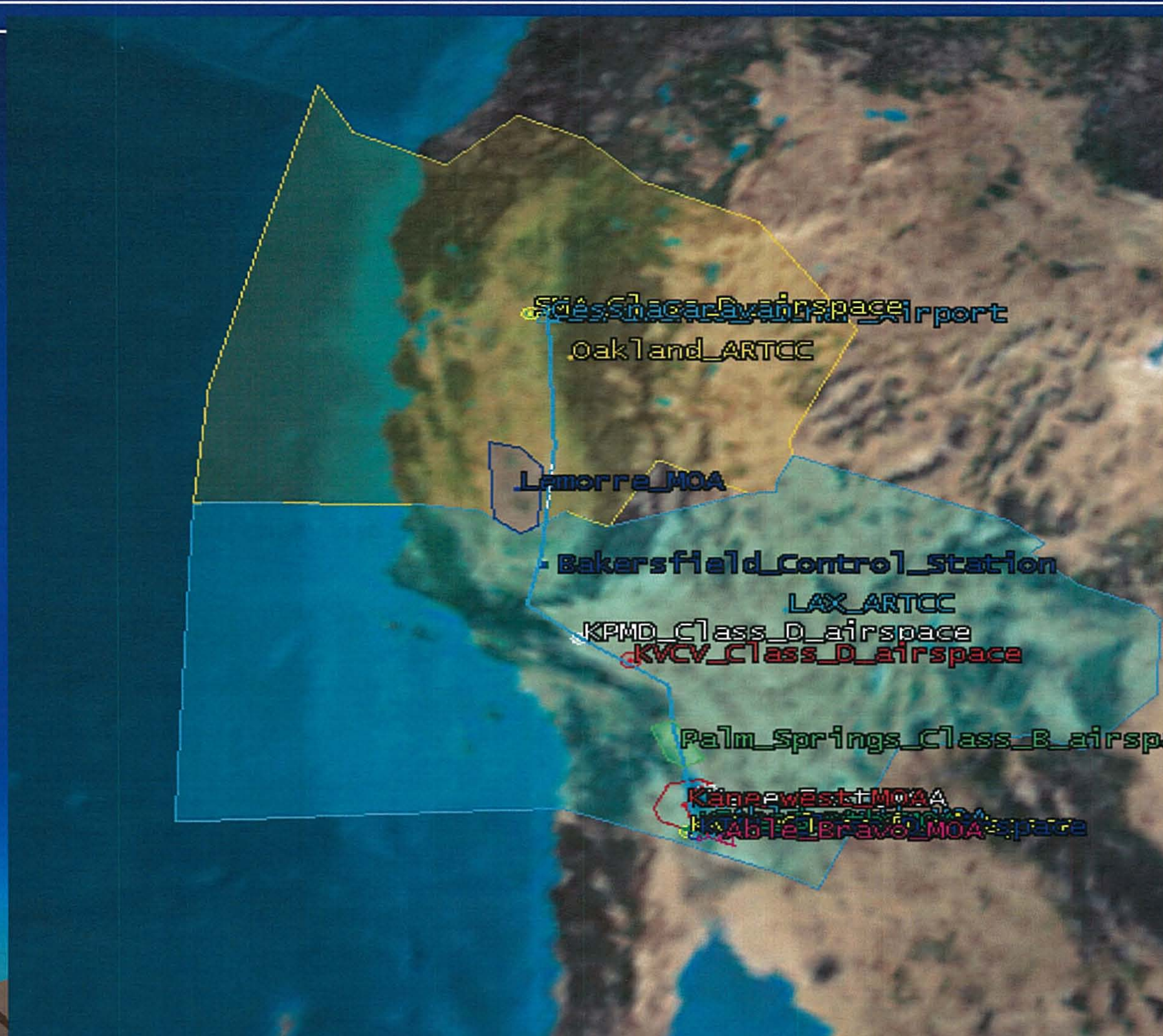
- Scenario 1 - Results
- There were many links calculated for this and the other scenarios. The rain was analyzed for 99.9% availability with rain rated of none, 20 mm/hr and 90 mm/hr at a height of 5 km out to 25 NM. This was done for each scenario for LOS and for BLOS links for Scenario 5 and 6. Scenario 1 was a LOS-only scenario.

- Use of two 3 dB Antennas on both ends. The CS2 was unable to maintain a control RF Link during the flight. The largest access gap periods between object top and bottom UA antennae were caused by terrain (ridges and hills). The CS Antenna was changed to High Gain Directional Antenna, all three CS maintained lock on vehicle.
- There were RF dropouts between the top and bottom UA antennae caused by aircraft obstructions (fuselage, wings, wheel assembles, etc.). Note that for this study antenna locations were placed on top and bottom center of the UA body. Future study should include actual UA antenna locations on the aircraft providing manufactures are willing to provide information.
- The importance of CS location(s) was demonstrated for primary or backup CS. With a second backup CS placed in a suitable location the UA was able to maintain an overall RF link. The actual location of both backup CSs required the antenna location to be place 150 ft above ground in order to establish a RF link between the UA and CS.

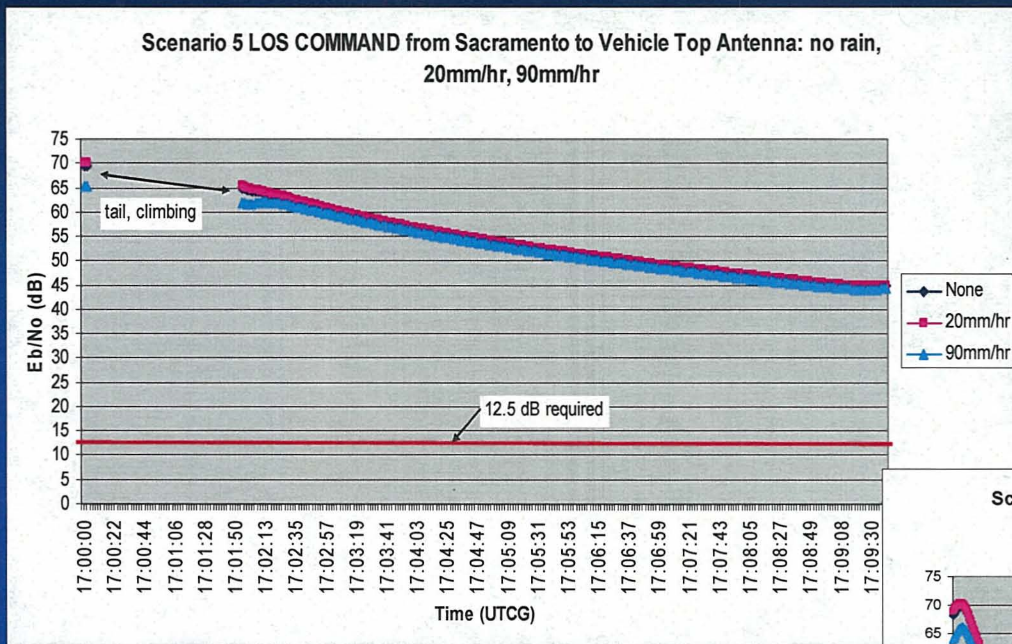
Scenario 5 Flight Overview

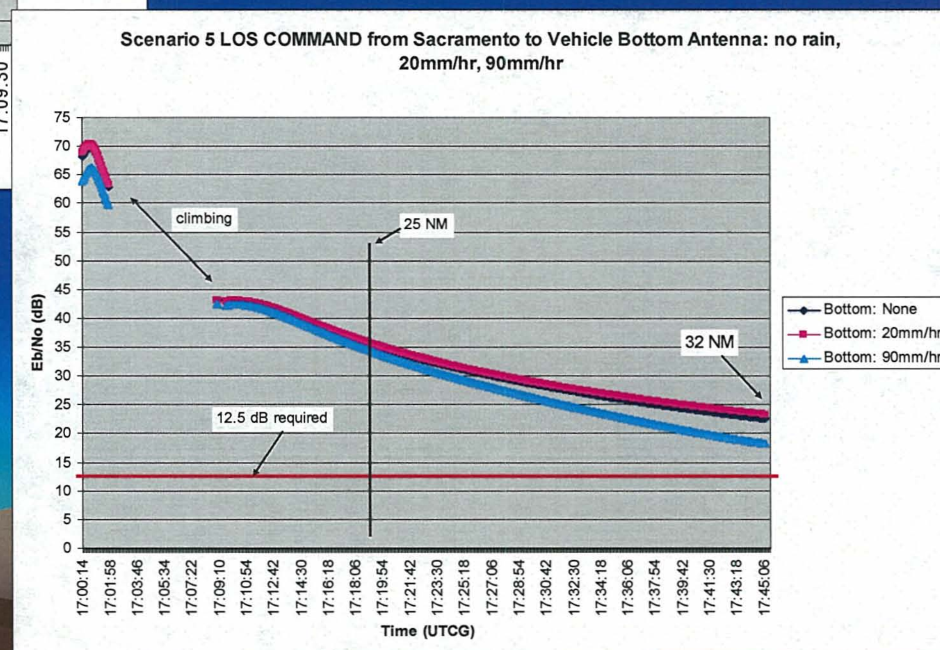


Scenario 5 Flight Overview

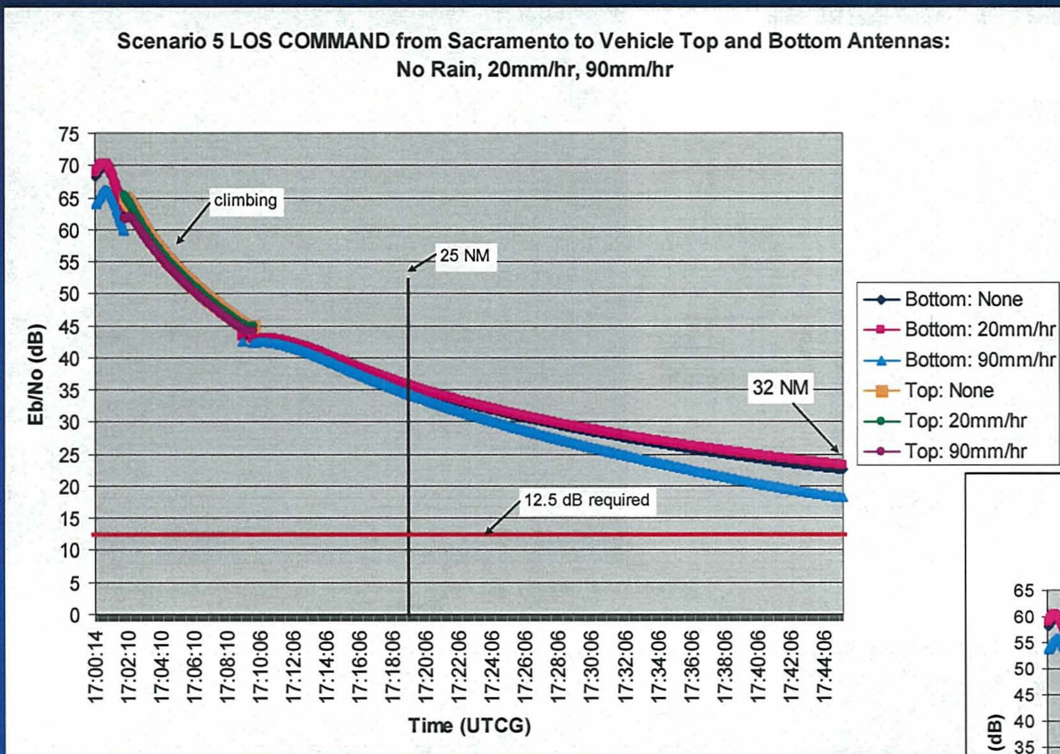


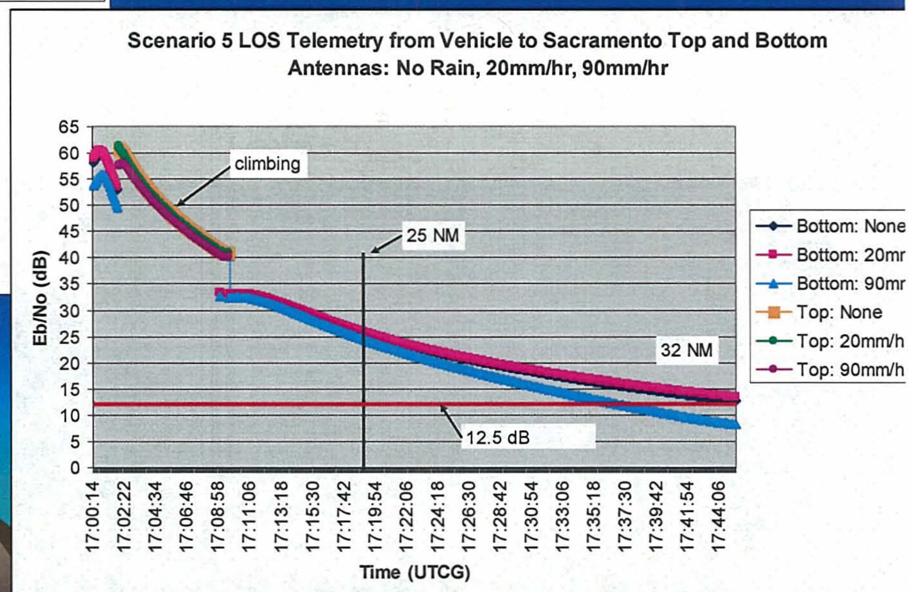
Top & Bottom Antenna



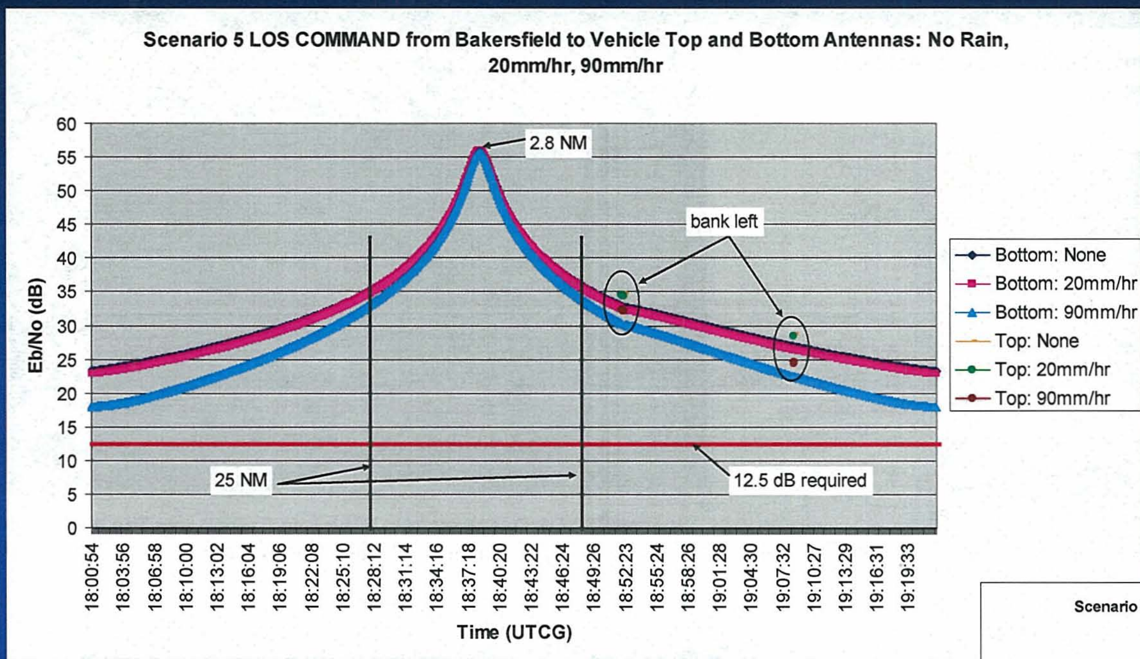


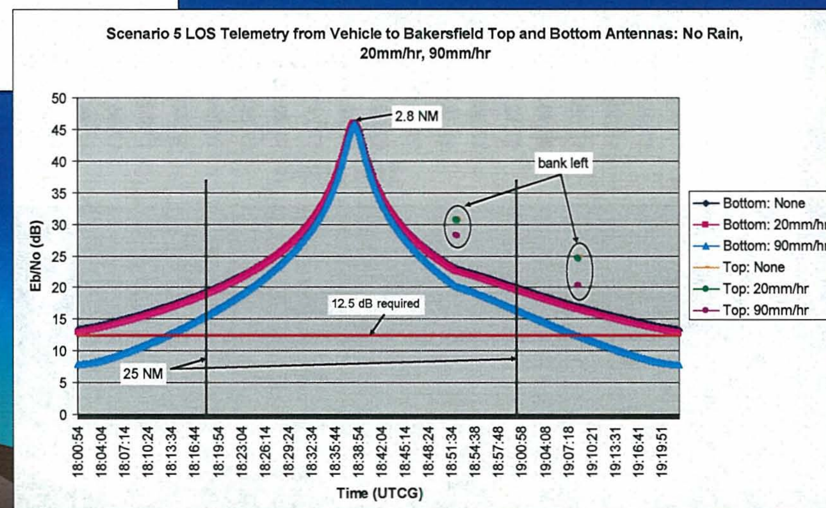
Combined Antenna Top & Bottom



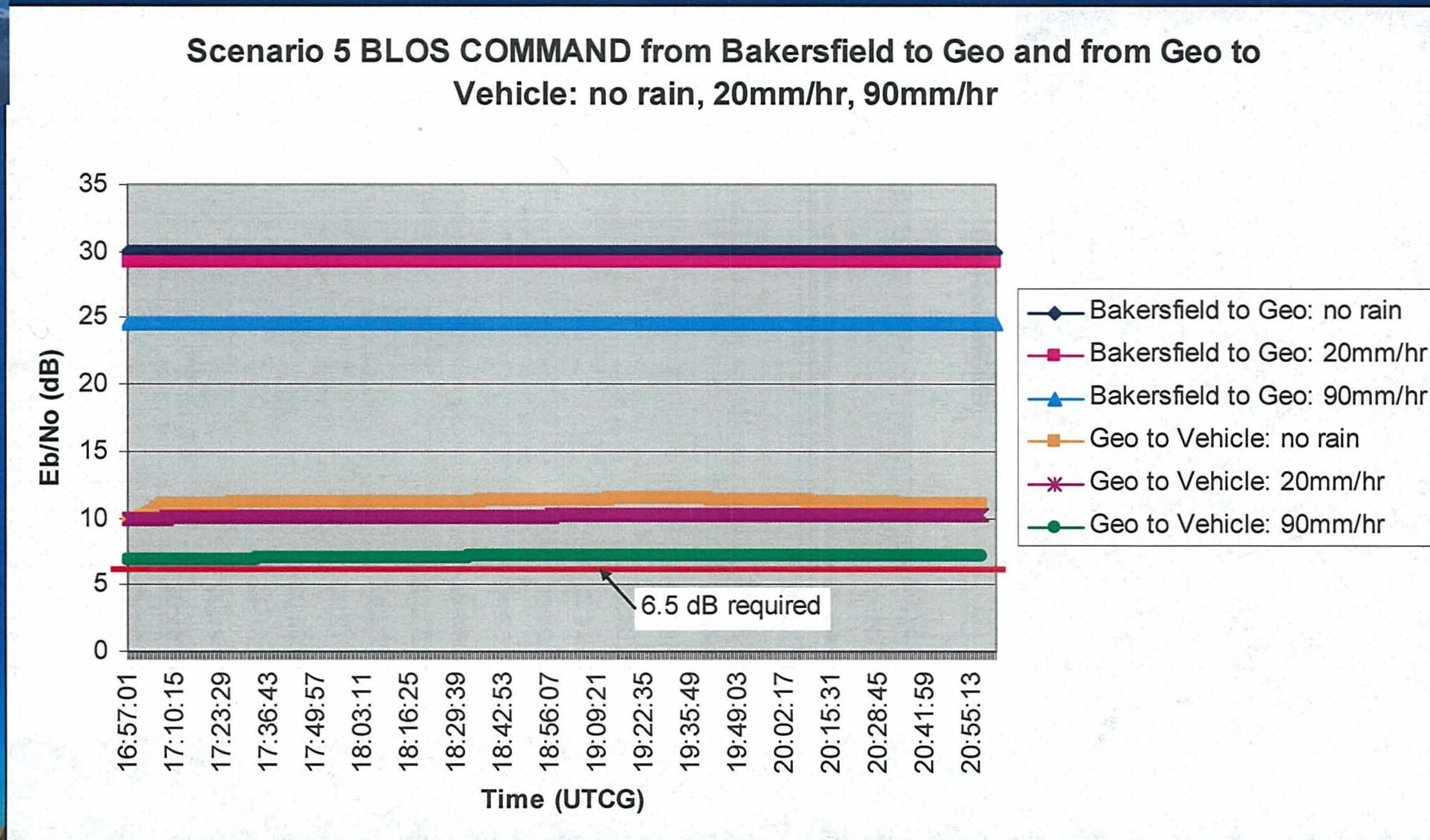


Bakersfield Command and Telemetry

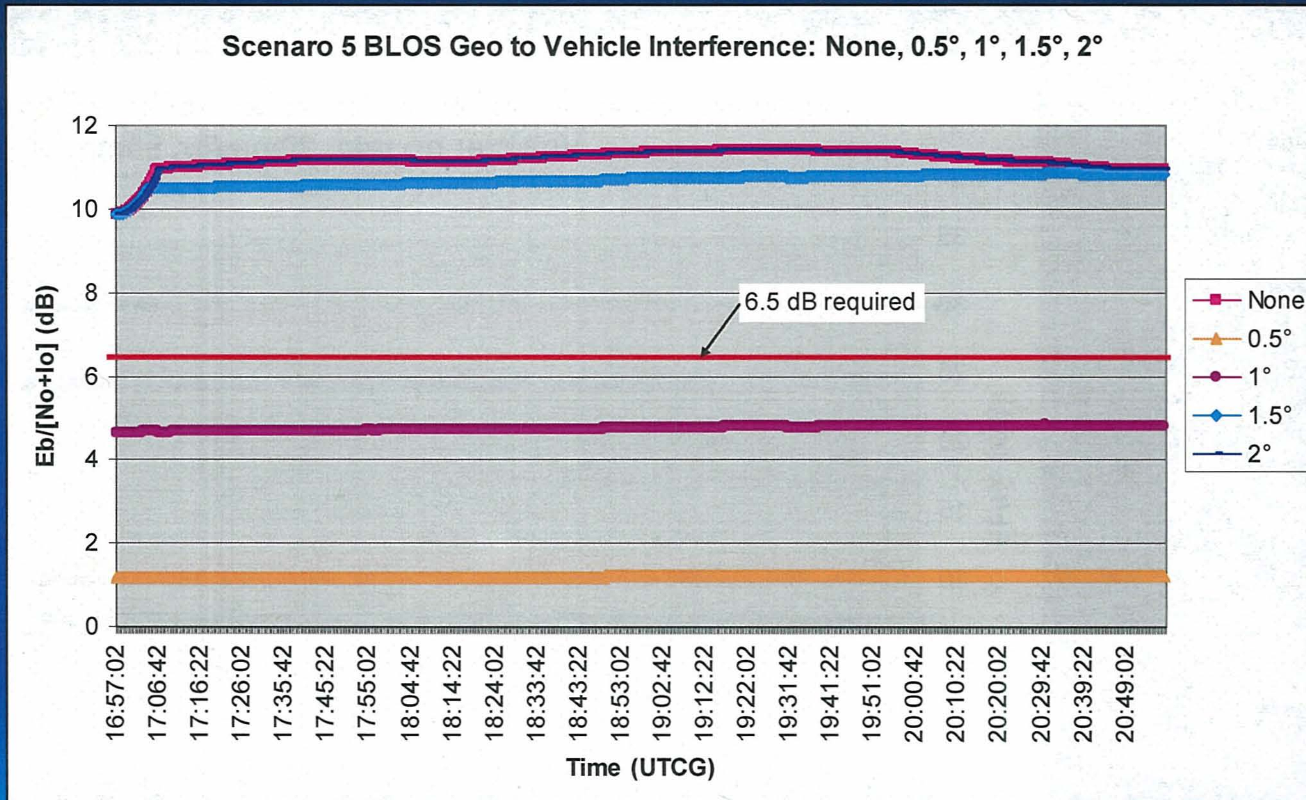




BLOS


Scenario 5 BLOS COMMAND from Bakersfield to Geo and from Geo to Vehicle: no rain, 20mm/hr, 90mm/hr
Eb/No (dB)
35
30
25
20
15
10
5
0
Bakersfield to Geo: no rain
Bakersfield to Geo: 20mm/hr
Bakersfield to Geo: 90mm/hr
Geo to Vehicle: no rain
Geo to Vehicle: 20mm/hr
Geo to Vehicle: 90mm/hr
6.5 dB required
16:57:01
17:10:15
17:23:29
17:36:43
17:49:57
18:03:11
18:16:25
18:29:39
18:42:53
18:56:07
19:09:21
19:22:35
19:35:49
19:49:03
20:02:17
20:15:31
20:28:45
20:41:59
20:55:13
Time (UTCG)

Interference



Qualnet Land Line

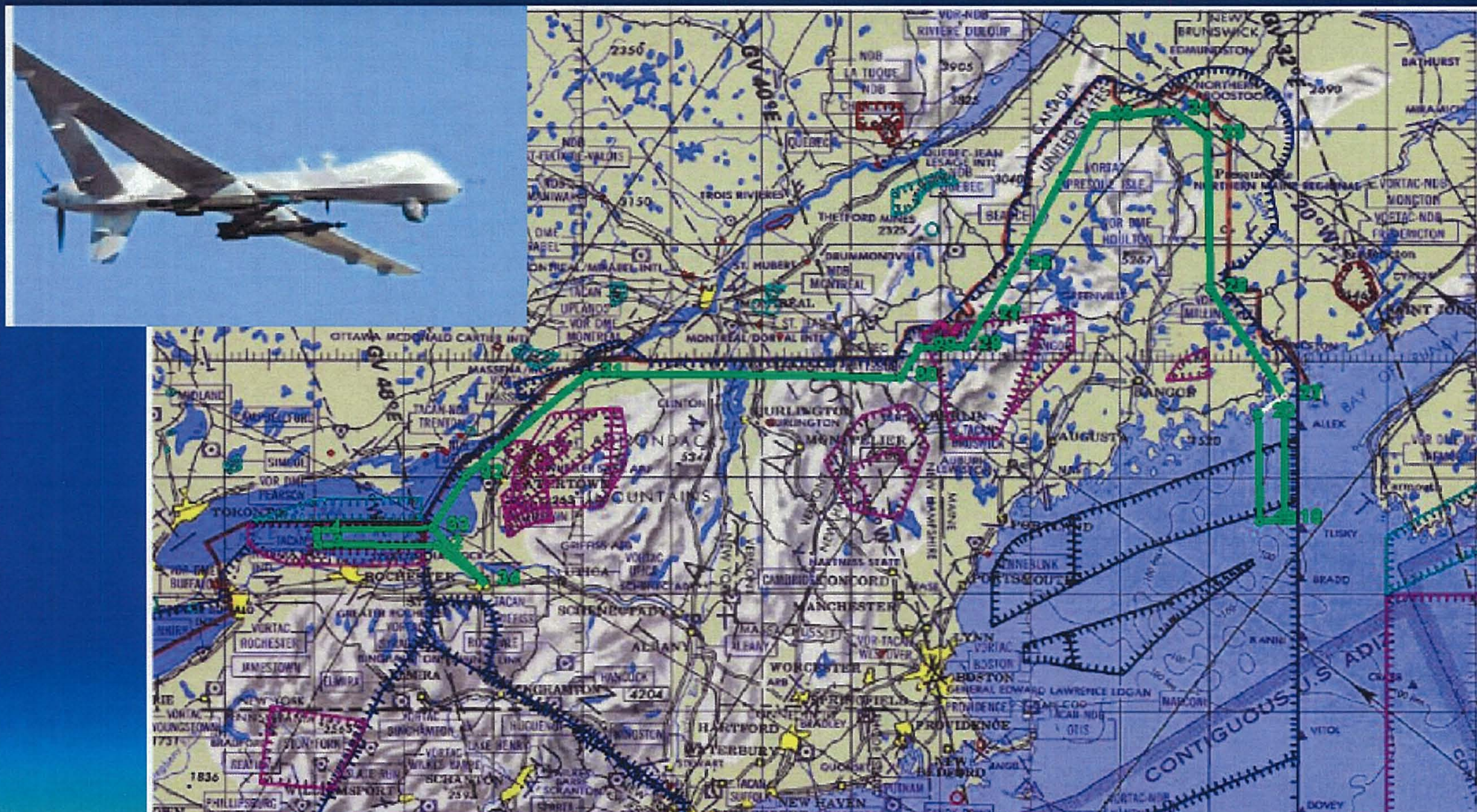
Qualnet was used on this scenario to analyze if there was any dropped packets and what the delay would be. This was a very high level approach to this analysis and will be further explored in the addendum to this report.
It was found that the delay were reasonable for a link to a GEO satellite, which the RF propagation is .128 seconds. The GEO to UA had a high jitter that resulted in a 1 packet loss. This will take more detailed analysis to determine why this was so since the signal strength was about the same for UA to GEO. (Propagation delay .125 seconds)

	BLOS			
	Command		Telemetry	
	CS to GEO	GEO to UA	UA to GEO	GEO to CS
Average Delay	0.13298	2.30570	0.13638	0.13298
Jitter	0.00260	0.20400	0.00343	0.00260
Maximum Delay	0.13041	0.40470	0.47267	0.38816
Packet Dropped	0	1	0	0

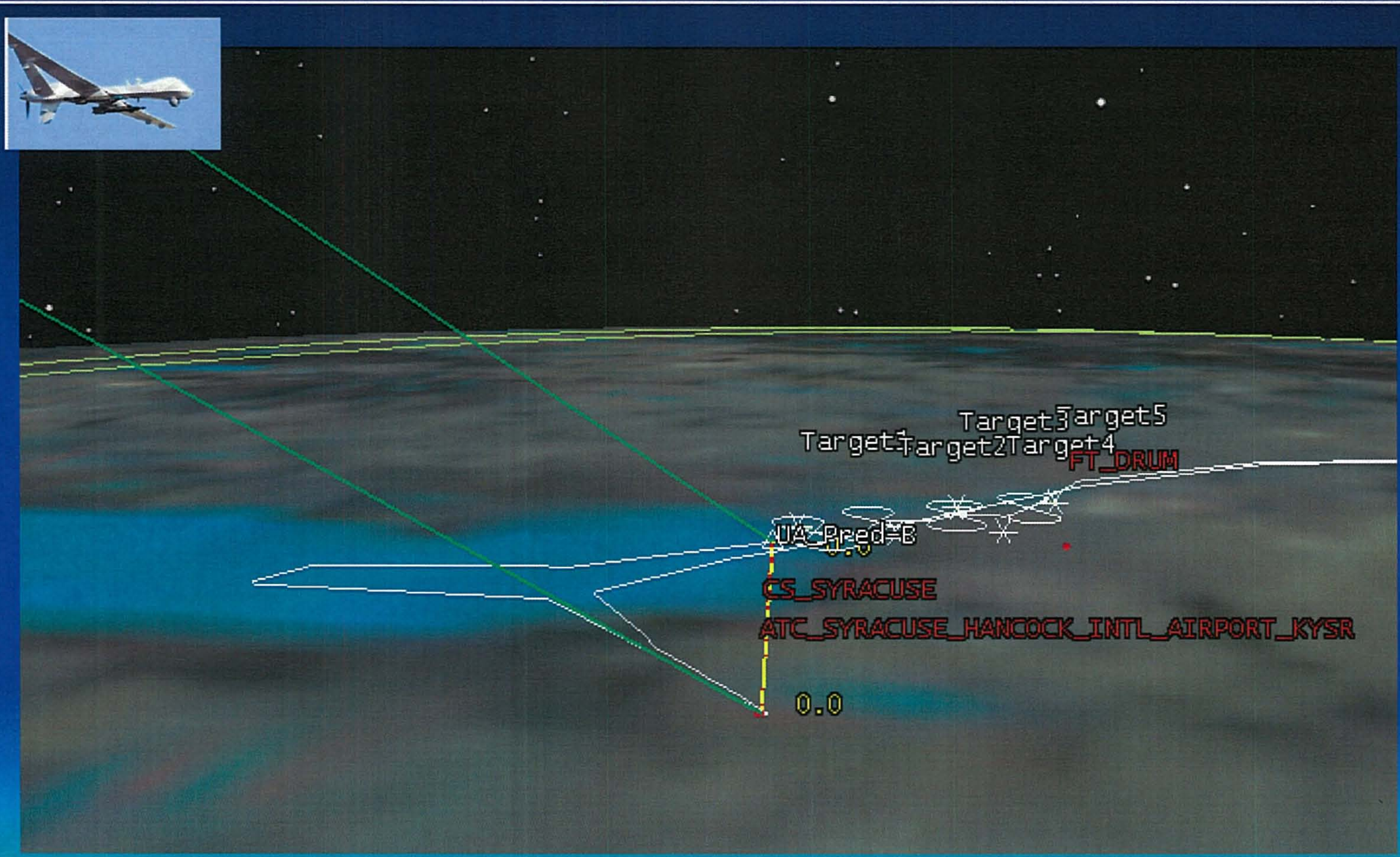
Scenario 5 Results

- Scenario 5 - Results
- The BLOS control link between the CS and UA was closed during the entire flight. The graphs followed fairly close to link calculations; for the LOS the calculations were done at 25 NM. Thus at 25 NM there is an excess margin of 25 dB. If we minus of the 20 dB multipath margin we are left with a 5 dB margin over that which is required. There is about a 5dB difference in the 90 mm/hr over the 45 minutes of the graph on the bottom telemetry antenna.
- Again, like Scenario 1 the combined LOS antennas do not show any drop outs.
- For the BLOS command link budget calculation there was a 21.2 dB excess margin. Unlike the LOS that was calculated for 25 NM, this link is calculated for a GEO satellite about 22,000 miles. These graphs will have more of a straight line over time since the range does not change that much as the UA flies its flight path. The graph for the command link shows about 20dB which is line with the link budget for command link.
- This scenario analyzed the affects of interference on the command link from the GEO to the vehicle from an adjacent satellite. An adjacent satellite was placed 2 degrees away from the GEO and then moved toward the GEO in 0.5 degree steps. There was no noticeable interference until the second GEO was 1.5 degrees and no adverse affect until the second GEO was 1 degree apart. This would degrade the performance down to about a 10-3 BER which is unacceptable.

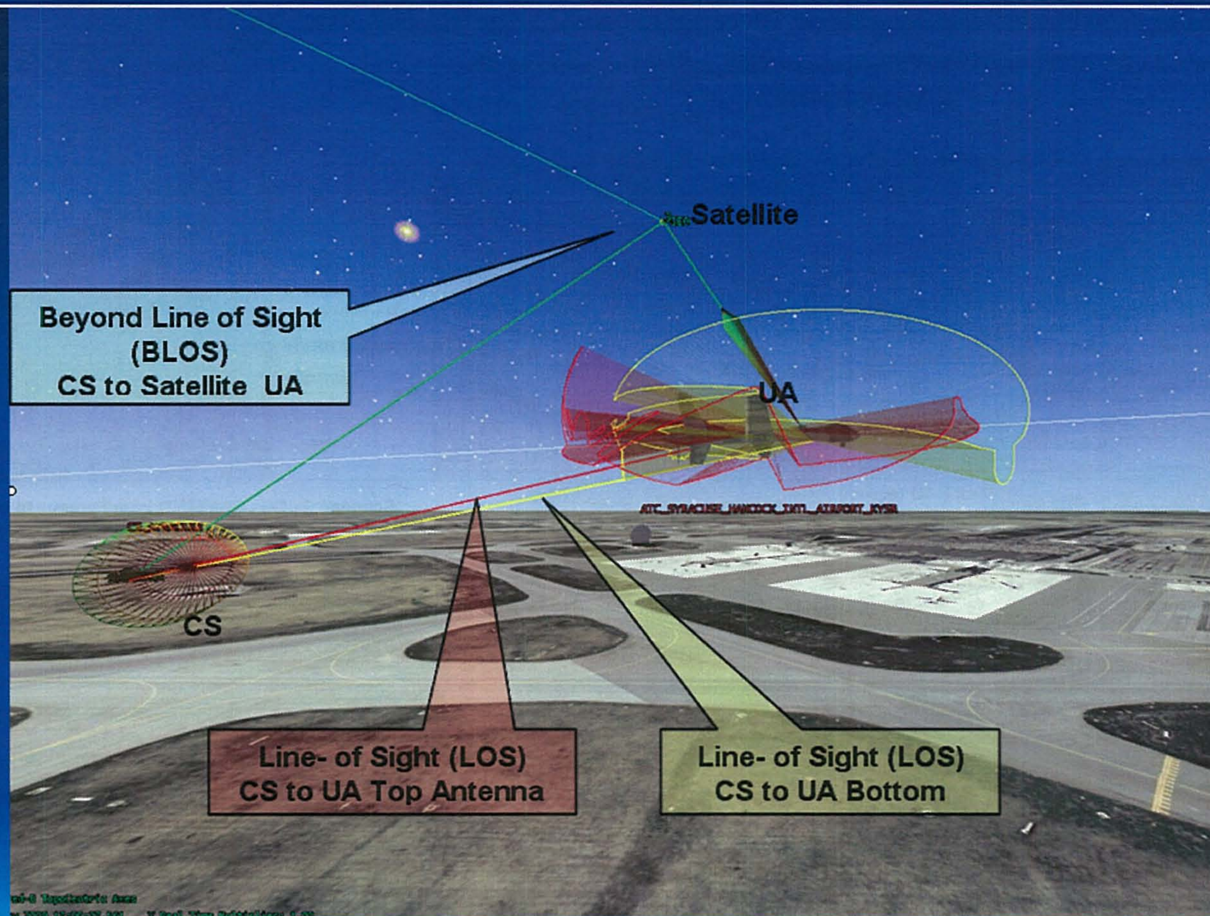
Scenario 6 Flight Overview



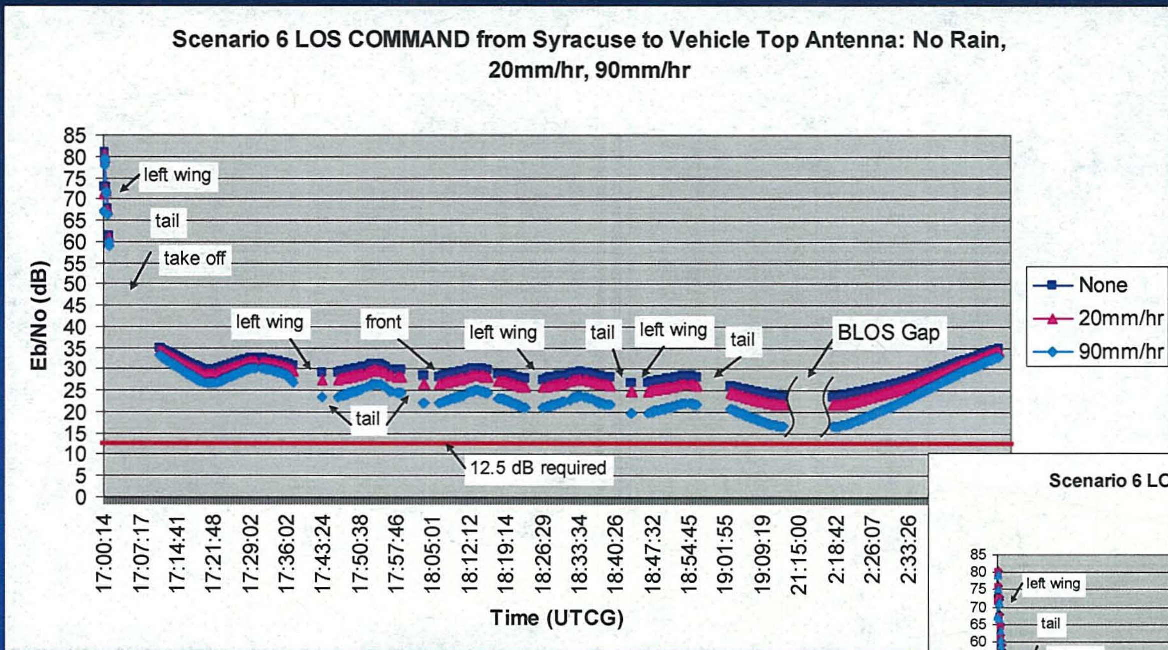
Scenario 6 Flight Overview

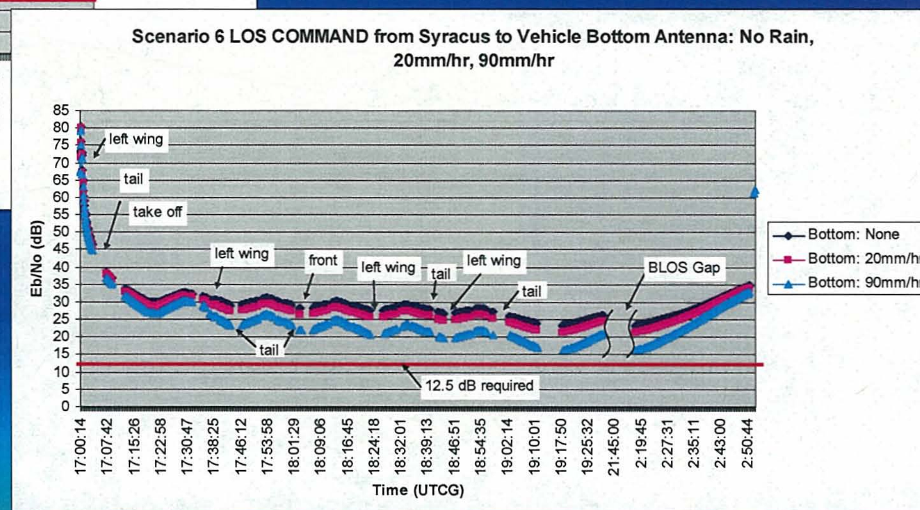


Scenario 6 Flight Overview

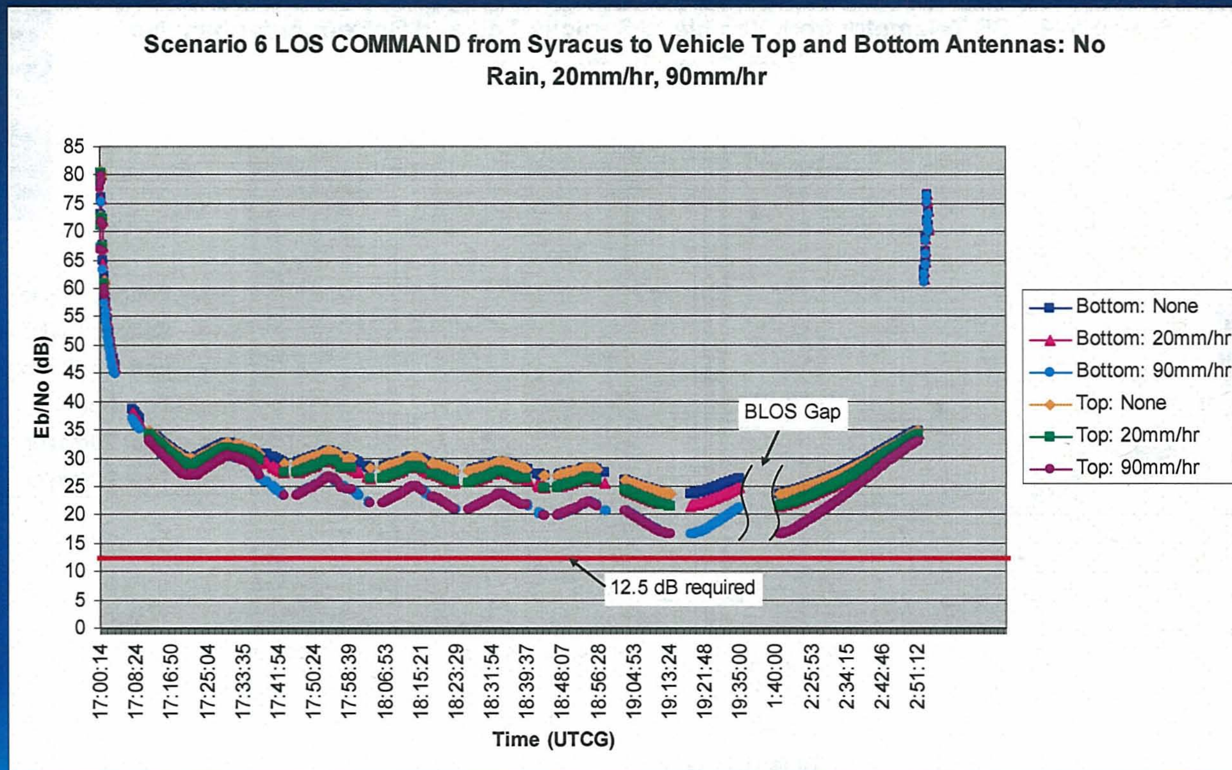


Scenario 6 Command

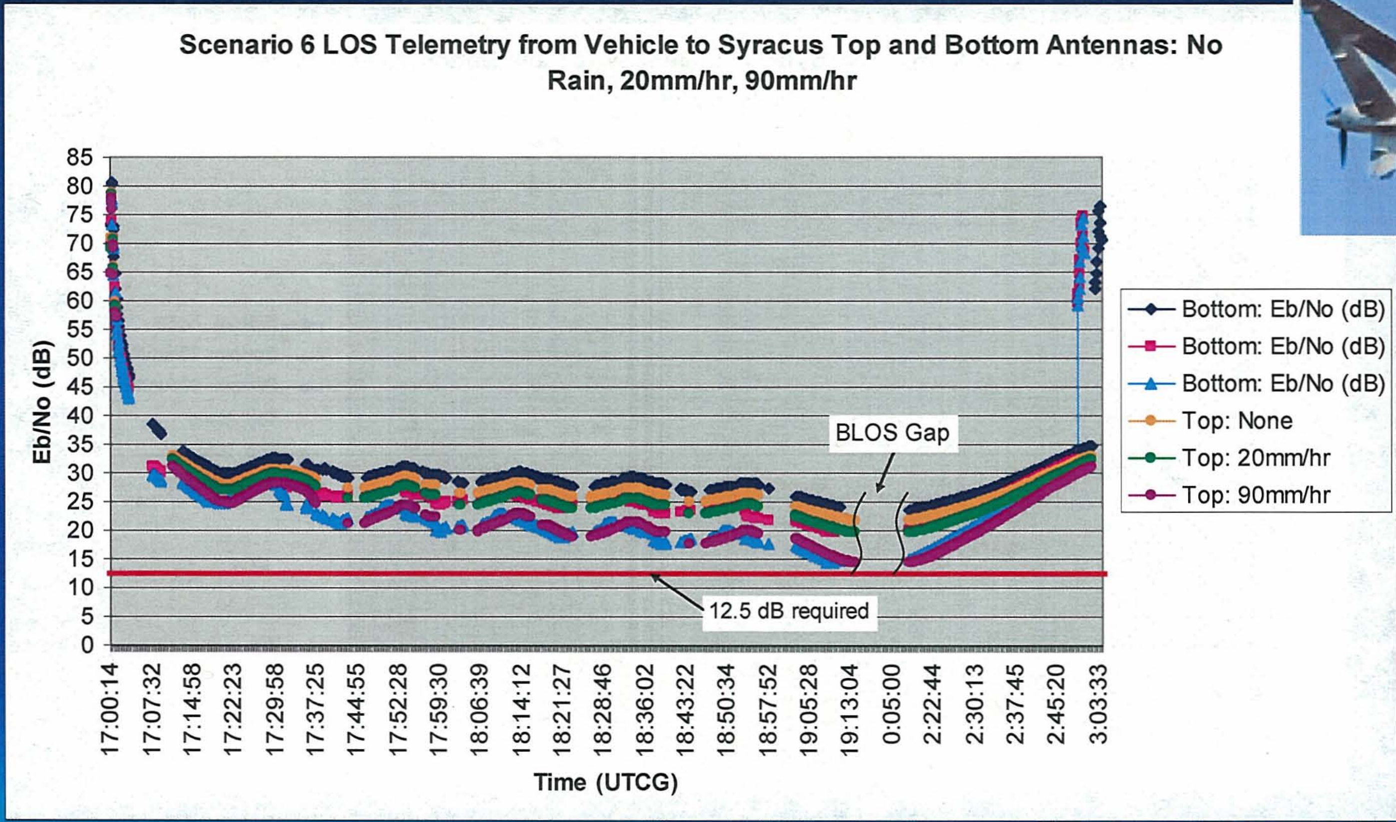




Scenario 6 Top & Bottom Antenna



Scenario 6 Telemetry Combined



Scenario 6 Results

- The LOS control link between the CS and UA dropped out during takeoff, landing and aerial maneuvers. The RF link dropouts occurred for both the top and bottom UA antennae and were caused by aircraft obstructions (fuselage, wings, wheel assembles, etc.). Note that for this study antenna locations were placed on top and bottom center of the UA.
- This can be compared to Scenario 1 were all three CSs are combined with top and bottom antennas there are no dropouts at all. This is critical and is one of the most important results of the paper.
- Scenario 6 BLOS follows along the same results as Scenario 5.
- The first graph is the CS up to the GEO. The calculated excess margin was 21.2 db and the graph shows 25 for no rain and 17 dB for the 90 mm/hr rain.
- Second graph is the command from GEO to the UA. It has a calculated excess of -0.65 and the graph shows an excess of gain of about 5 for no rain and about 0.5 dB for the 90 mm/hr rain.
- The third graph is telemetry for the UA up to the GEO. The calculated excess margin is 11.88 dB whereas the graph shows about 2 dB for no rain and a -1 dB for 20 mm/hr and down to 0 for 90 mm/hr. This link would fail during a heavy down poor and be of about 10-4 BER for moderate rain of 20 mm/hr.
- The fourth and final graph is from the GEO to the CS at Syracuse. The calculated excess margin is 15.13 dB whereas the graph shows about 18.5 db, and the heavy rain is about 5 dB less or 0r 13.5 dB.
- Overall the STK Simulations performed as was calculated in the section on link margins.

Scenario1 ScanEagle and Raven
RF Link Access / Gap Comparison

Raven

ScanEagle

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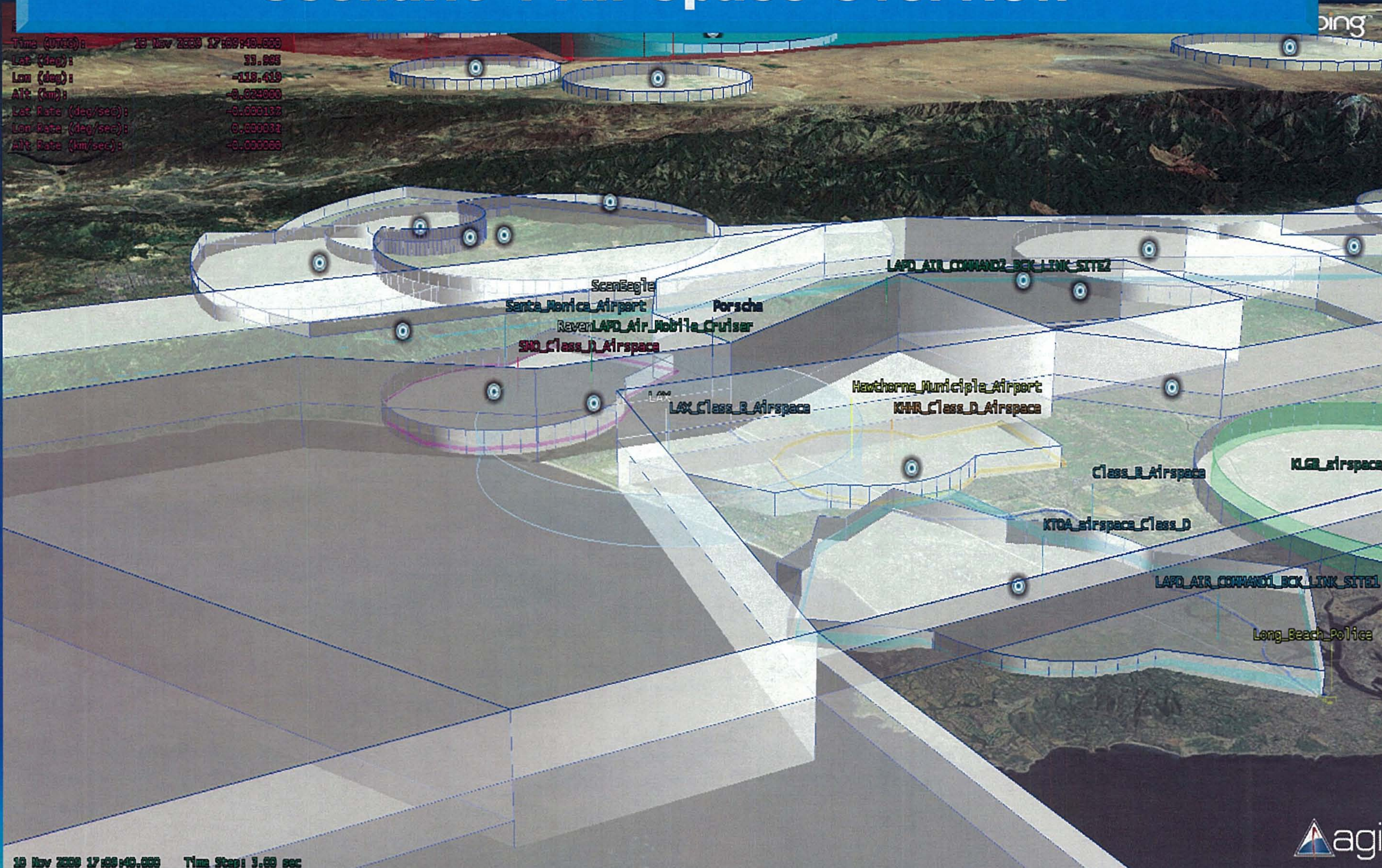
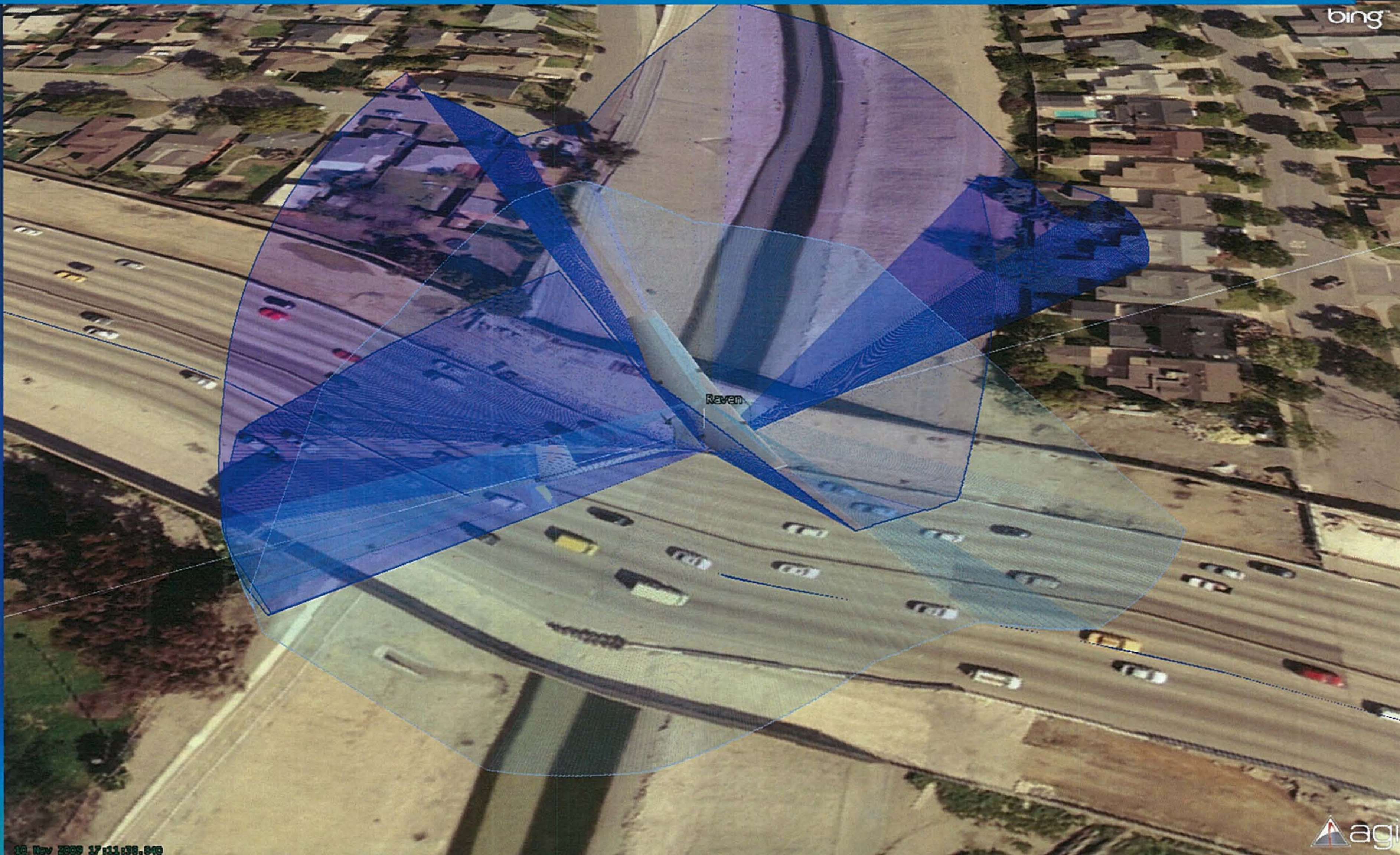
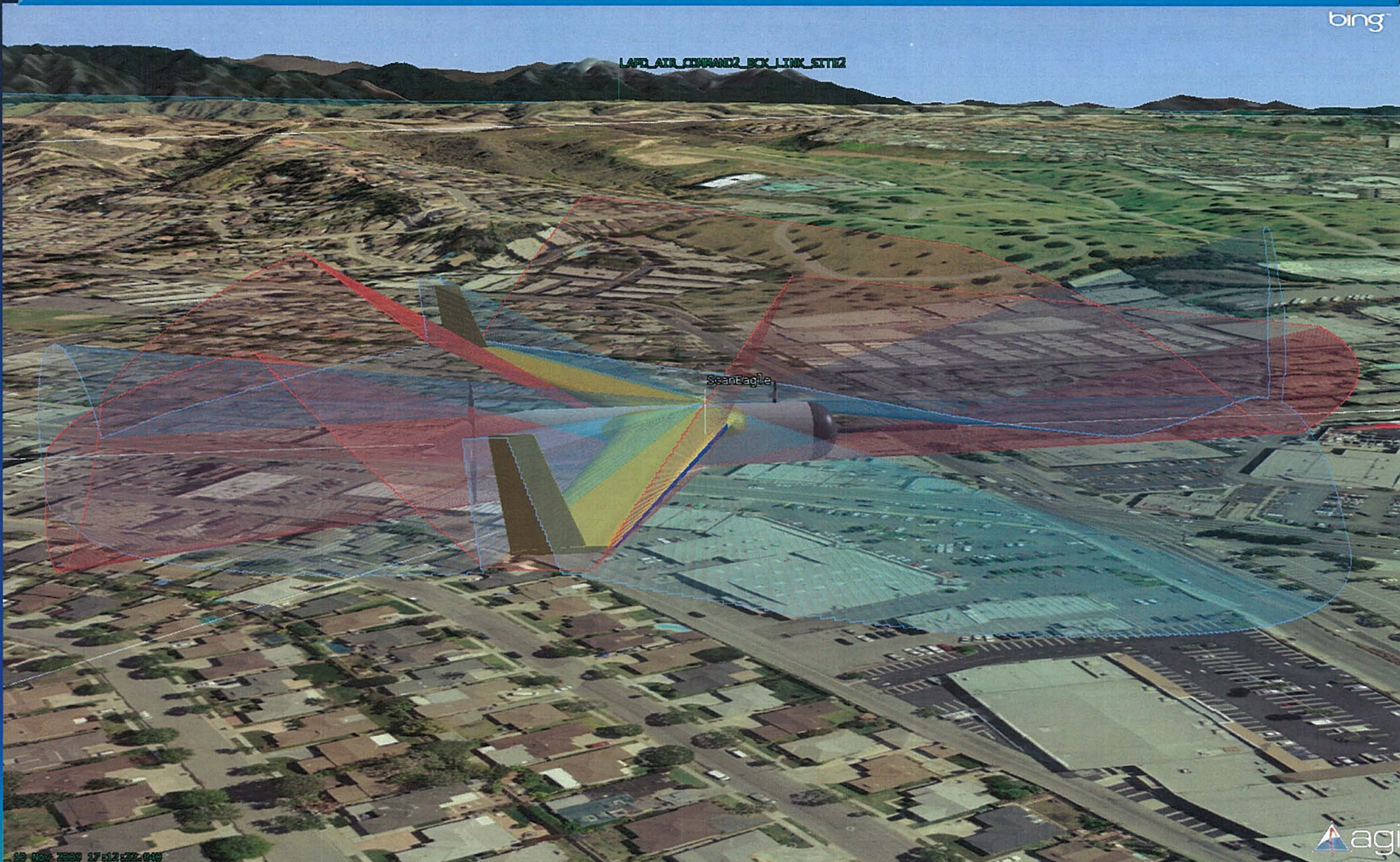
Scenario 1 Air Space Overview



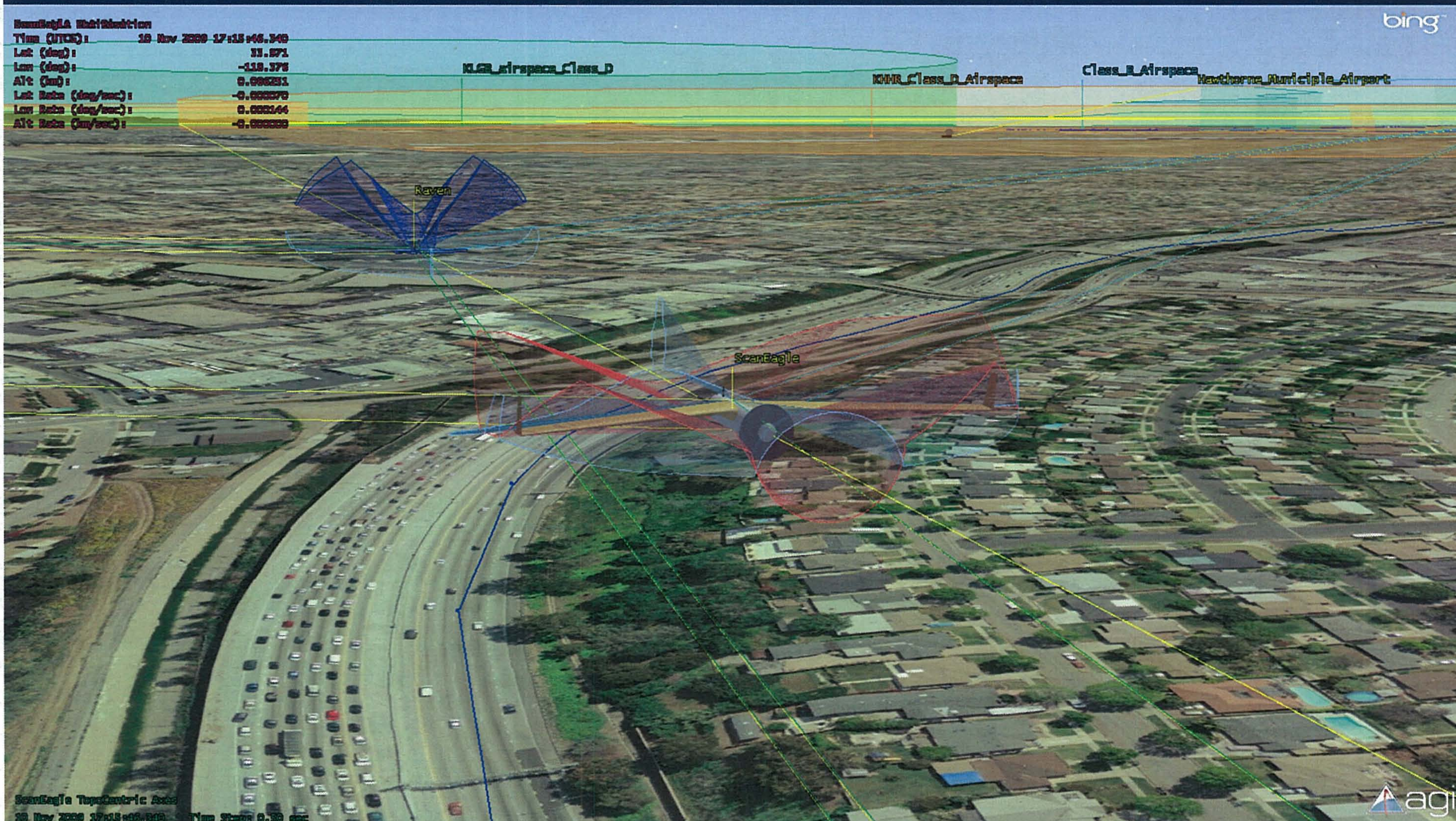
Raven Antenna Mask



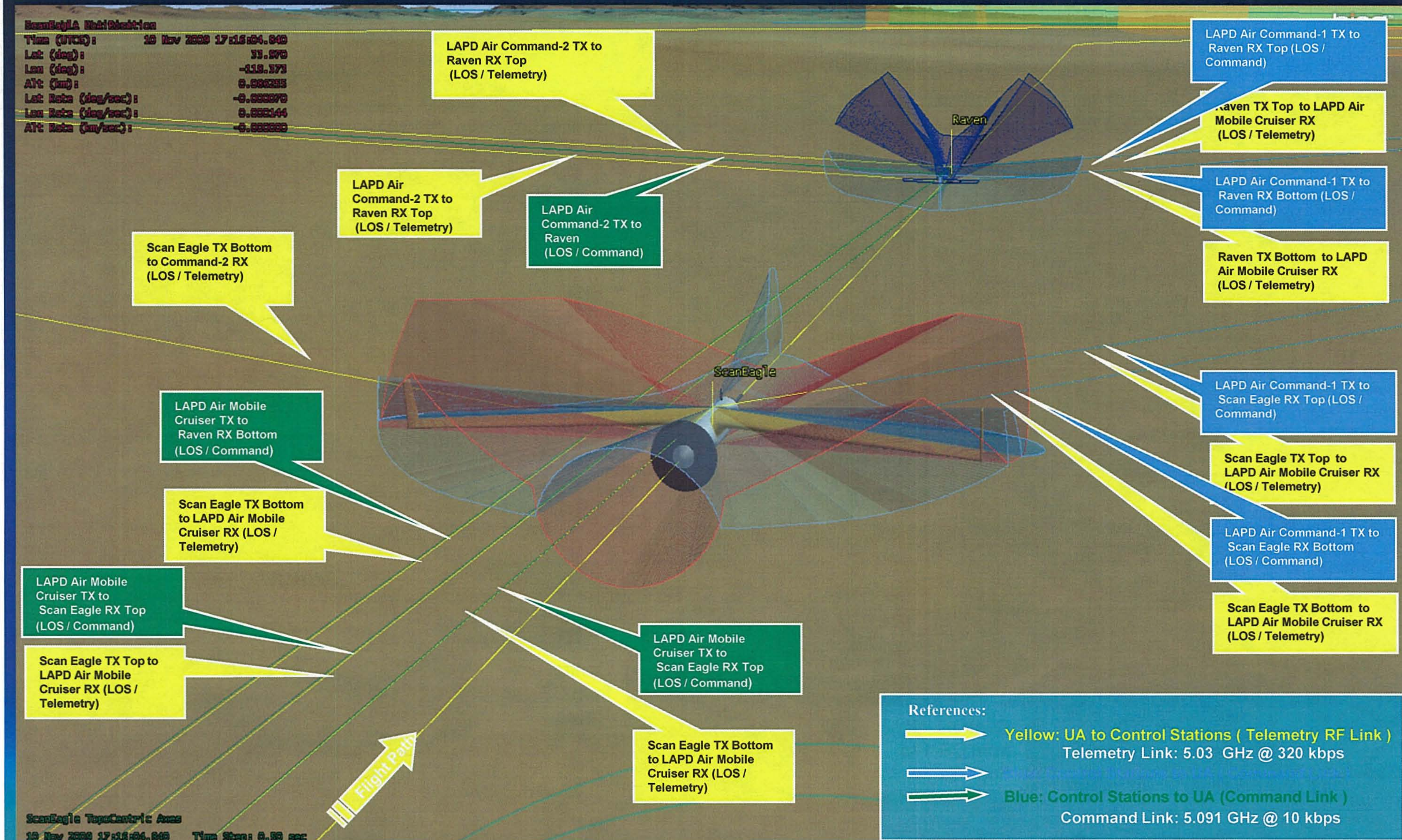
ScanEagle Antenna Mask



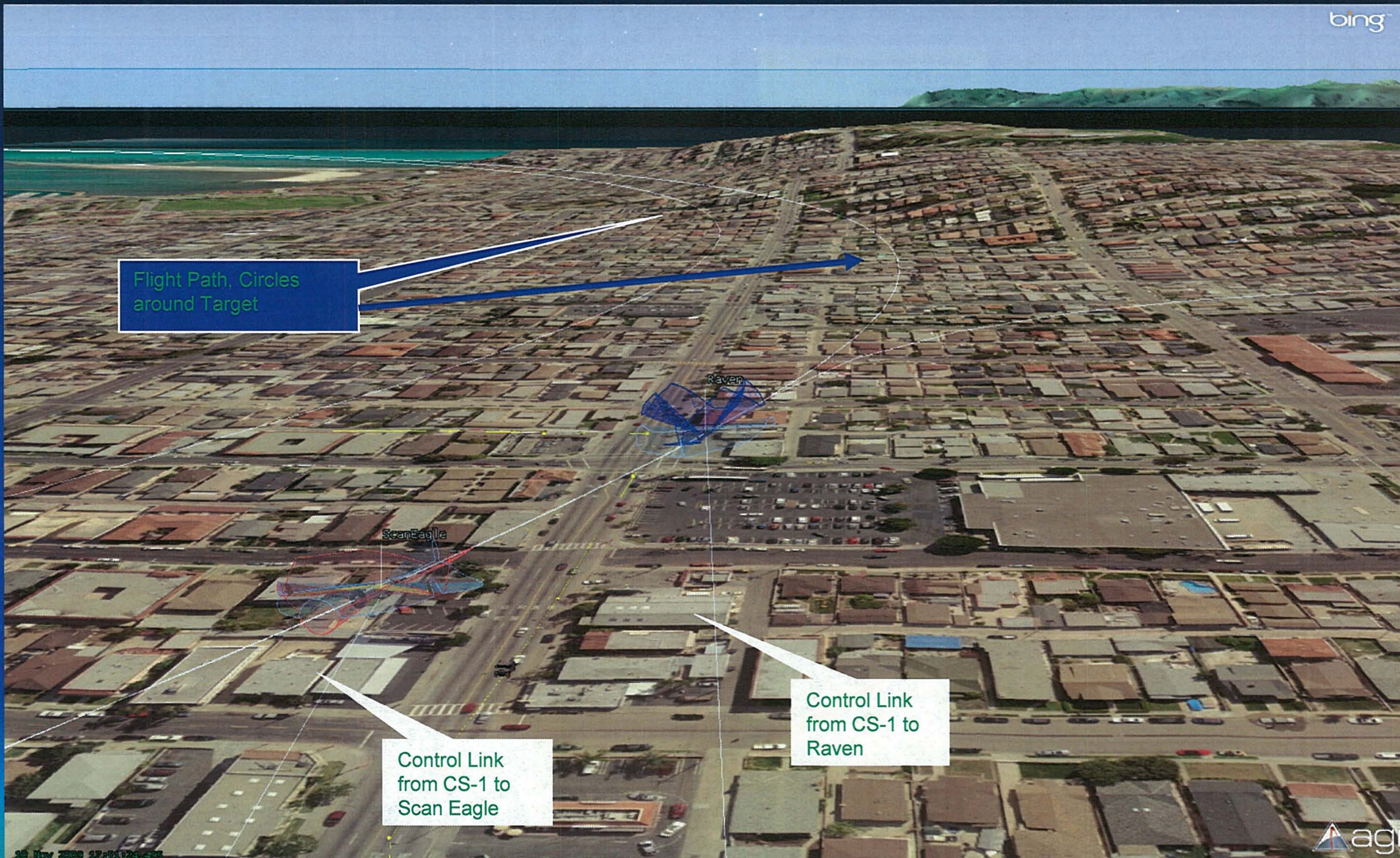
ScanEagle & Raven Antenna Mask with RF Links



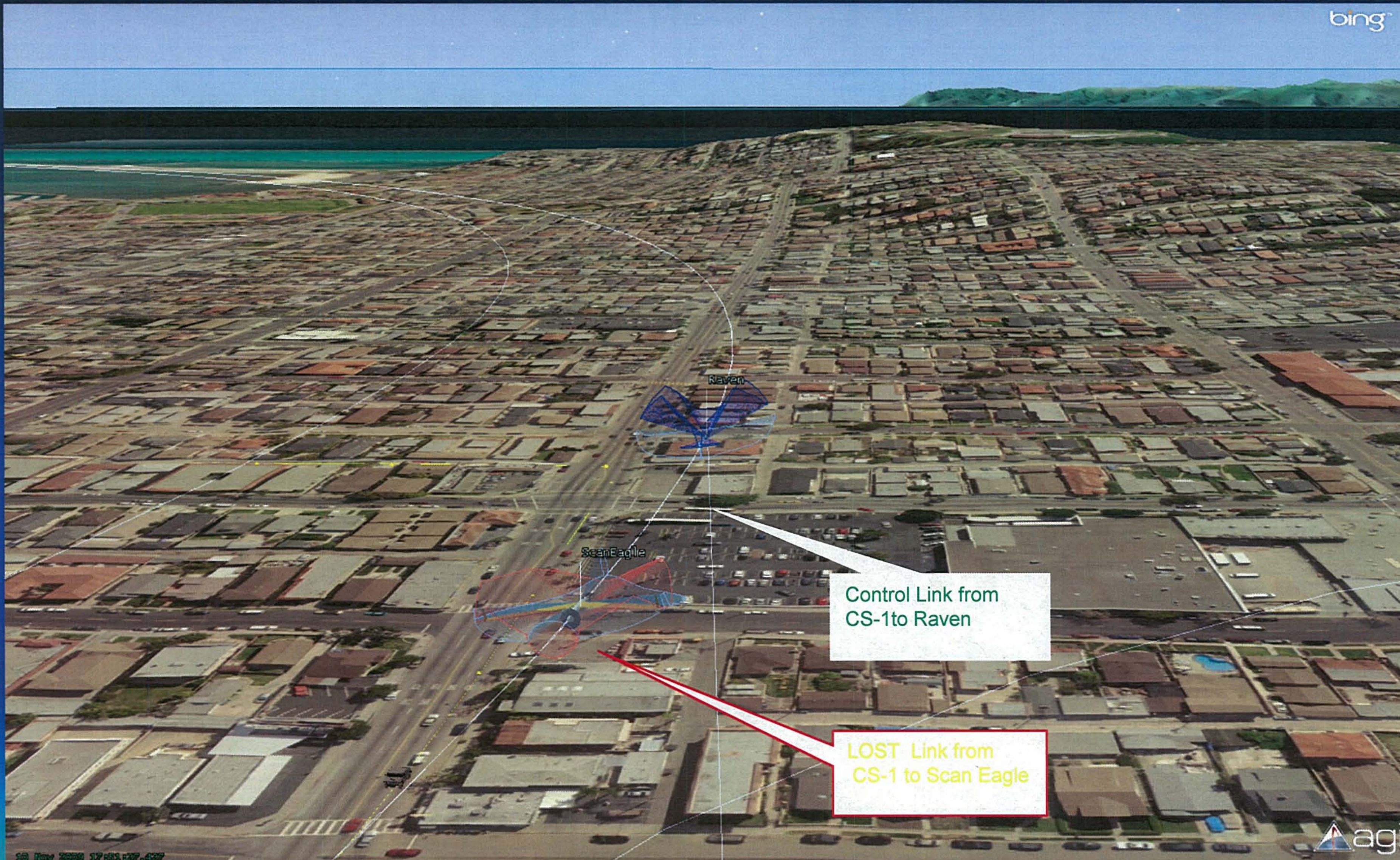
ScanEagle & Raven Antenna Mask with RF Links, *Continue*



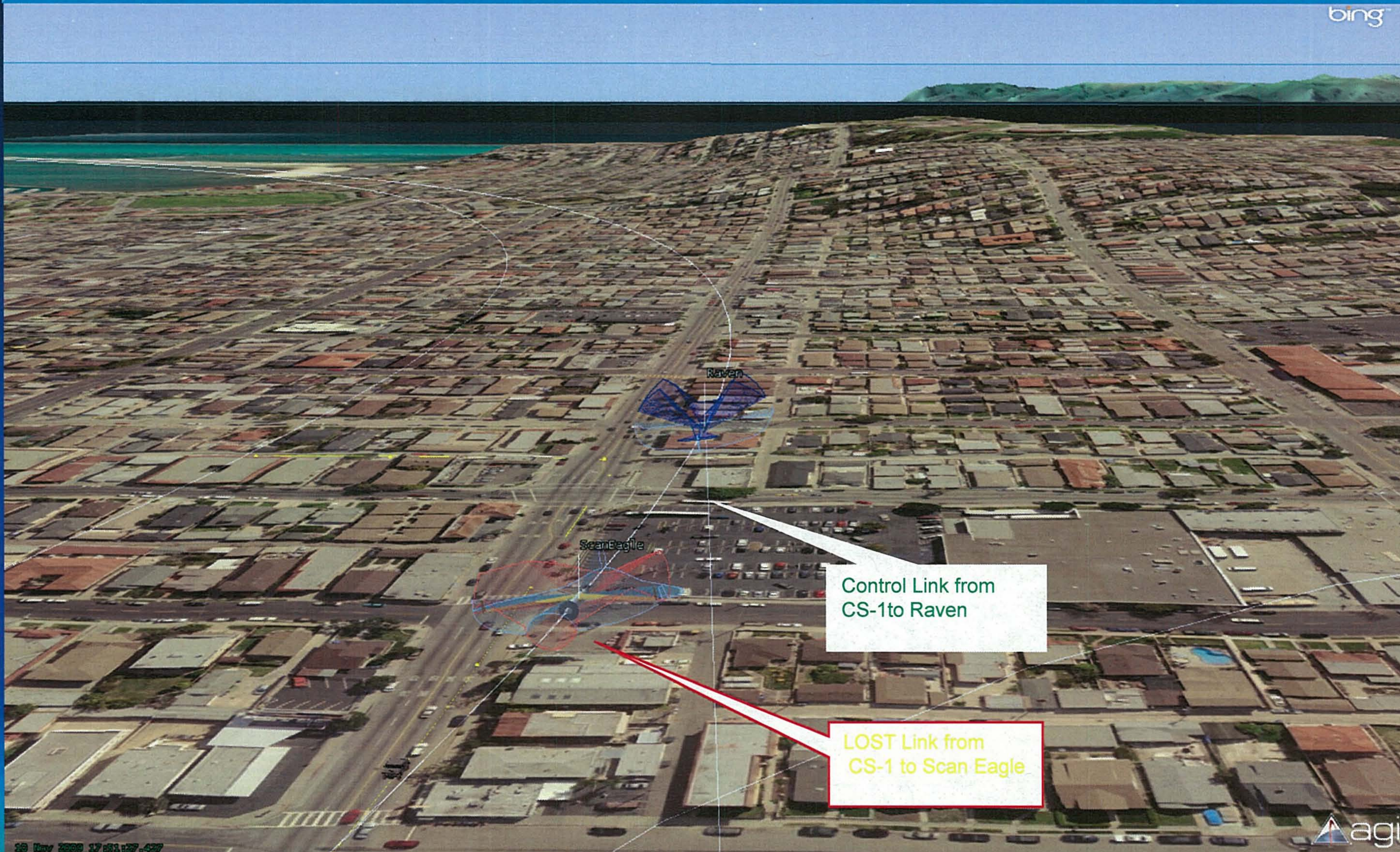
ScanEagle & Raven Telemetry Links between CS-1



Raven Telemetry Link between CS-1, ScanEagle (LOST Link)

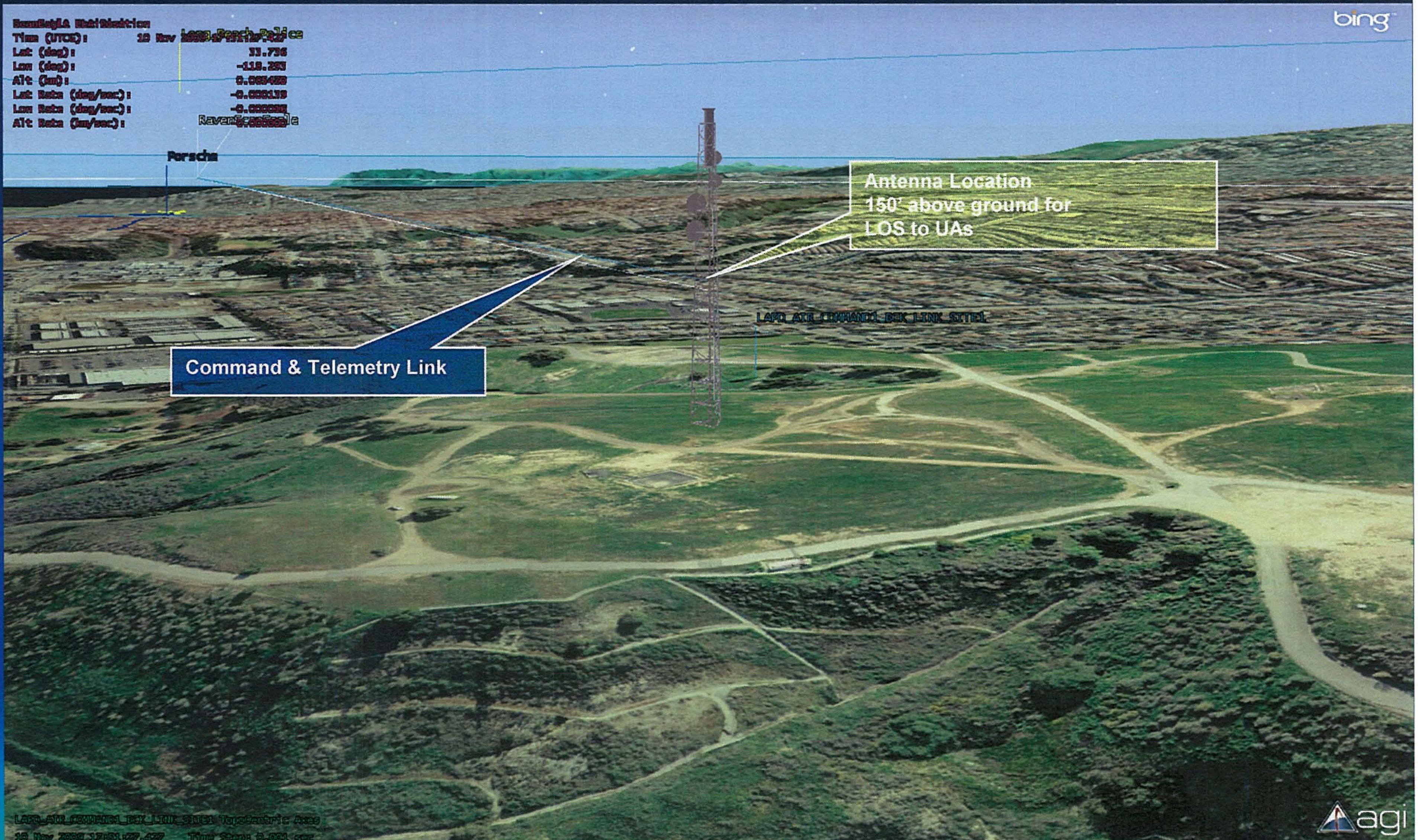


ScanEagle & Raven Lost Link

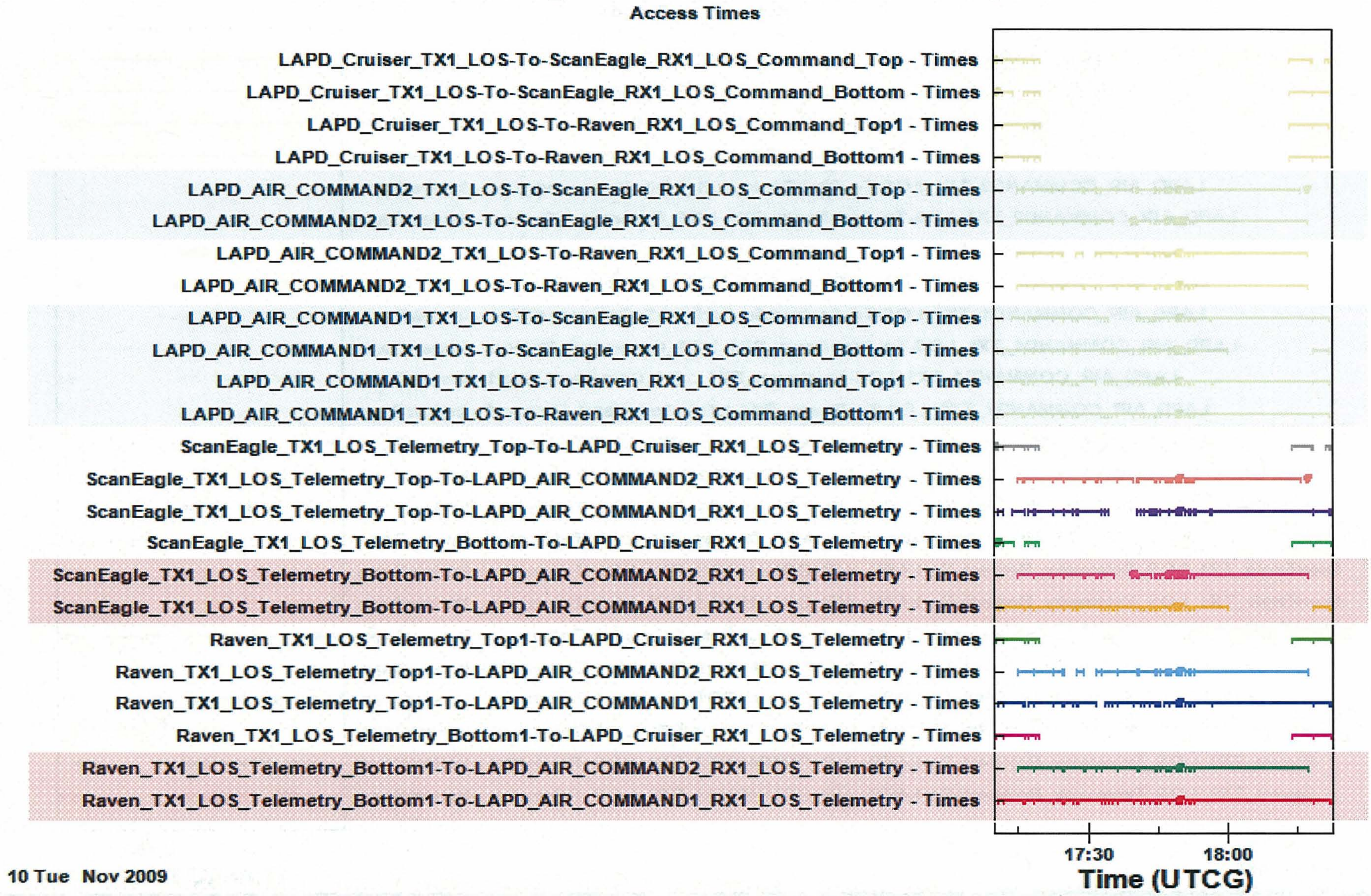


Raven LOST Link and ScanEagle LOST Link between CS-1

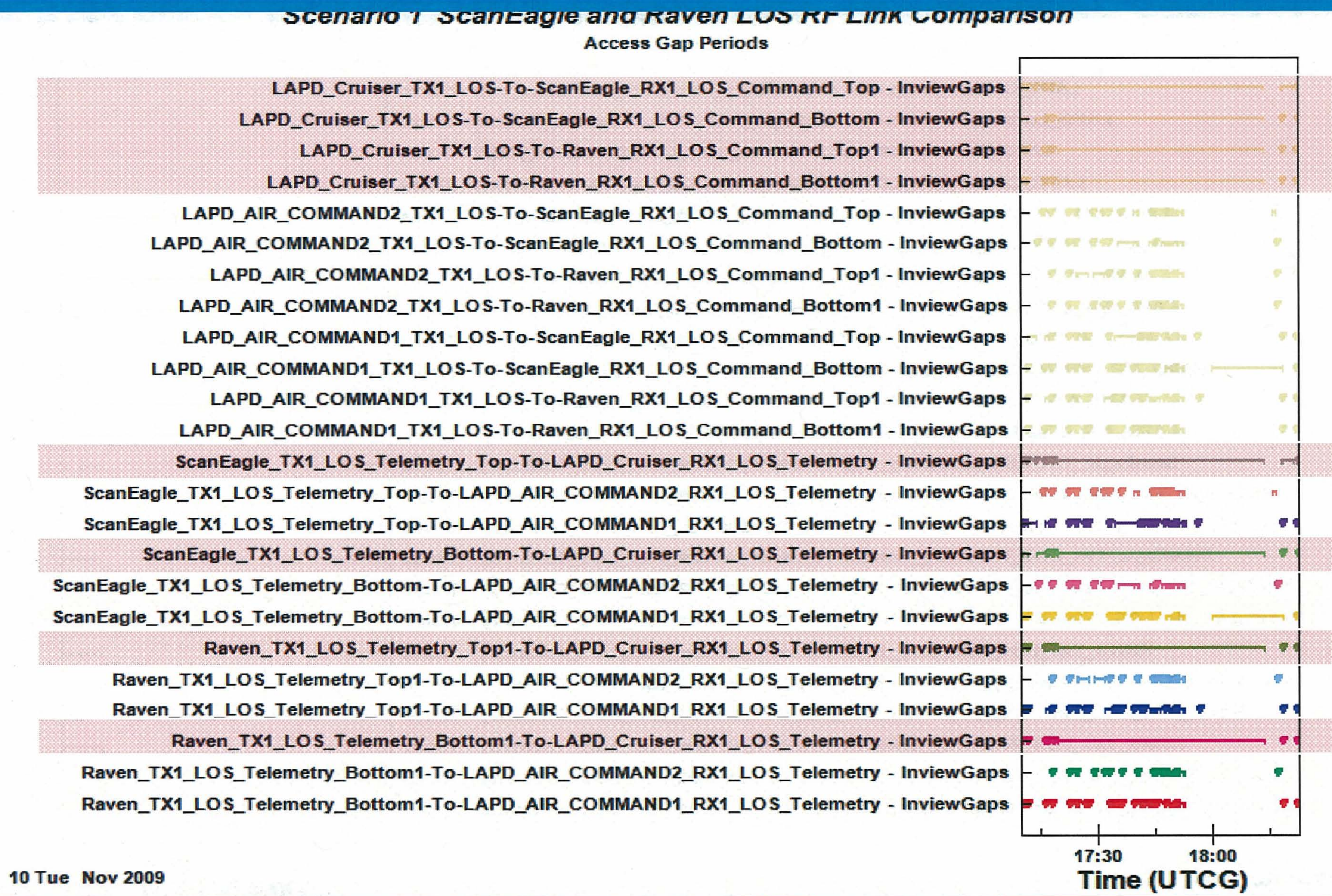
Raven Command & Telemetry Link to CS-1 (Antenna Height)



Example: ScanEagle & Raven Access Time



Example ScanEagle & Raven Access Gap Periods



Example: GAP Period Statistics for Scenario 1 ScanEagle

Facility: LAPD Air Mobile Cruiser Transmitter TX1 To UA: ScanEagle Receiver RX1 Top (LOS / Command)

Individual GAP Statistics for Scenario 1

Facility: LAPD Air Mobile Cruiser Transmitter TX1 To UA: ScanEagle Receiver RX1 Top (LOS / Command)

Scenario Start Time	Scenario Stop Time
11/10/2009 17:09	11/10/2009 18:22

Gap	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)	Percentage (%)
1	09:40.0	09:59.8	19.845	0.5726
2	10:07.1	10:07.3	0.109	0.0031
3	10:08.2	10:17.1	8.97	0.2588
4	10:17.3	10:17.7	0.423	0.0122
5	10:24.3	10:24.5	0.167	0.0048
6	10:25.1	10:26.3	1.246	0.036
7	11:50.6	11:51.9	1.294	0.0373
8	11:52.1	11:54.7	2.543	0.0734
9	13:54.7	13:54.9	0.175	0.005
10	16:12.3	16:12.4	0.171	0.0049
11	16:12.5	16:14.9	2.395	0.0691
12	16:59.6	17:02.4	2.831	0.0817
13	18:33.2	18:35.5	2.313	0.0667
14	19:45.4	13:37.7	3232.287	93.2596
15	17:58.5	18:13.2	14.673	0.4234
16	18:24.4	21:07.6	163.218	4.7092
17	22:02.2	22:02.7	0.485	0.014
18	22:14.0	22:26.7	12.758	0.3681
Total			3465.903 ~ 58 Min.	100%

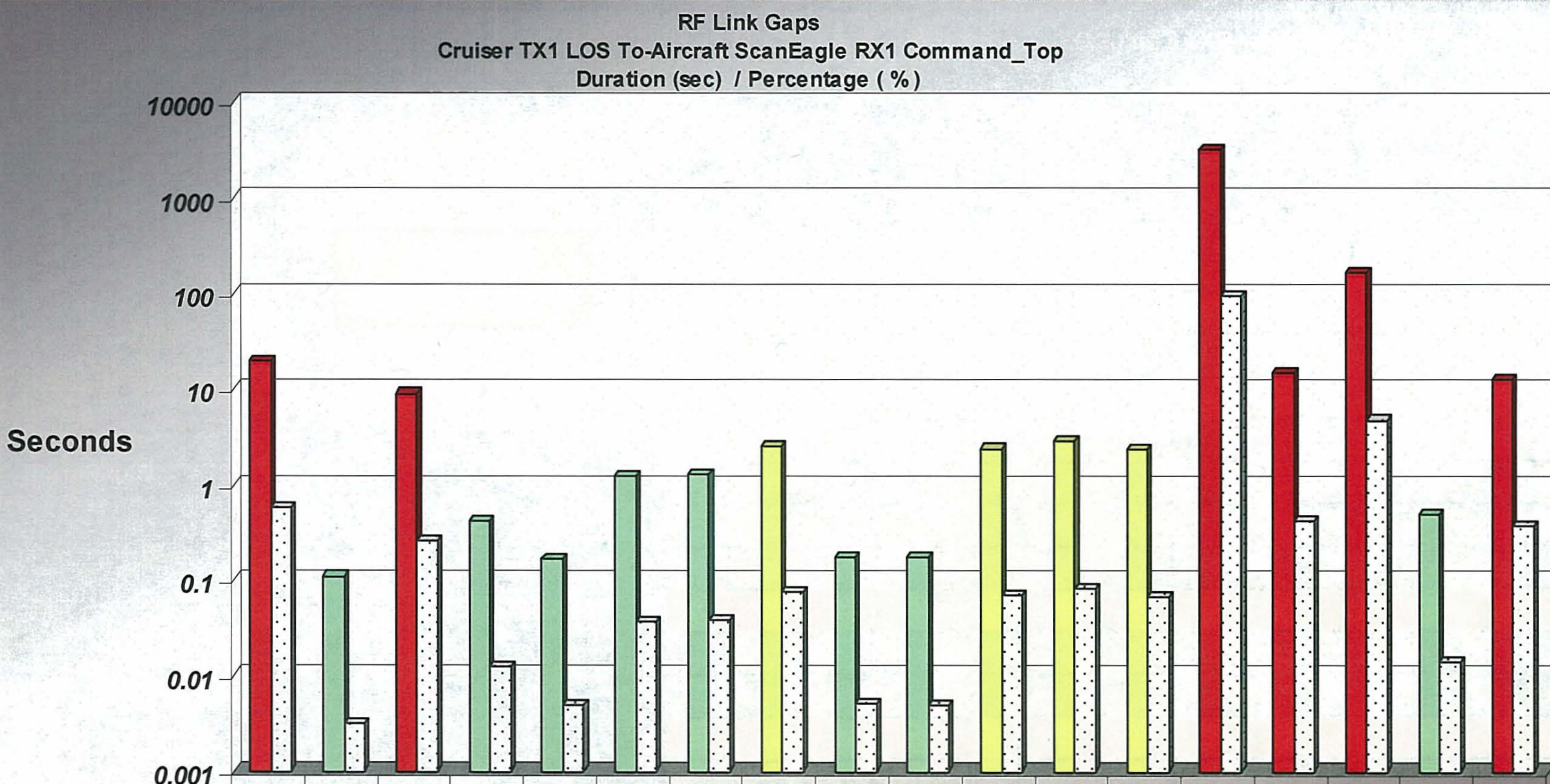
Global Statistics

Reference	Quantity	Sub Total Gap Times
Gaps Greater Than or Equal to 3 sec	6	3451.751
Gaps Greater Than 2 sec & Less Than 3 sec	4	0.2909
Gaps Less Than 2 sec	8	0.1173

Reference	Gap	Gap Period (sec)
Min Duration	2	0.109
Max Duration	14	3232.287
Mean Duration		192.55
Total Duration		3465.905

Example: GAP Period Statistics for Scenario 1 ScanEagle

LAPD Air Mobile Cruiser Transmitter TX1 To ScanEagle Receiver RX1 Top (LOS Command)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Duration (sec)	19.85	0.109	8.97	0.423	0.167	1.246	1.294	2.543	0.175	0.171	2.395	2.831	2.313	3232	14.67	163.2	0.485	12.76
Percentage (%)	0.573	0.003	0.259	0.012	0.005	0.036	0.037	0.073	0.005	0.005	0.069	0.082	0.067	93.26	0.423	4.709	0.014	0.368

Example: GAP Period Statistics for Scenario 1 Raven
LAPD Air Mobile Cruiser Transmitter TX1 To UA: Raven Receiver RX1 Top (LOS / Command)

Individual GAP Statistics for Scenario 1

Facility: LAPD Air Mobile Cruiser Transmitter TX1 To UA: Raven Receiver RX1 Top (LOS /) Command

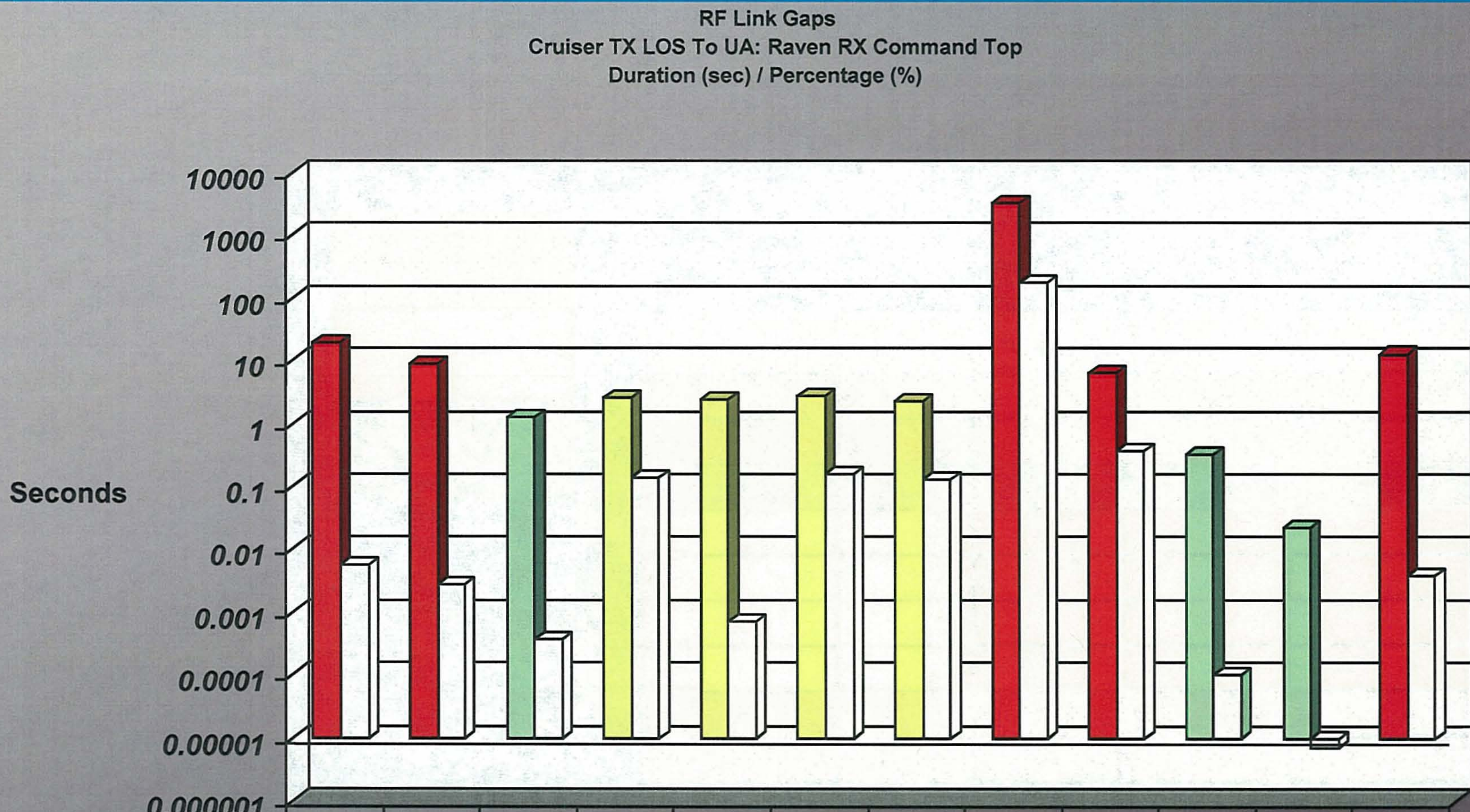
Scenario Start Time	Scenario Stop Time
11/10/2009 17:09	11/10/2009 18:22

Gap	Start Time (UTCG)	Stop Time (UTCG)	Duration (sec)	Percentage (%)
1	09:40.0	09:58.8	18.846	0.0057
2	10:07.2	10:16.1	8.972	0.0027
3	10:24.1	10:25.3	1.246	0.0004
4	11:51.1	11:53.7	2.542	0.1412
5	16:11.5	16:13.9	2.395	0.0007
6	16:58.6	17:01.4	2.831	0.1573
7	18:32.2	18:34.5	2.313	0.1285
8	19:45.4	13:37.7	3232.287	179.5715
9	18:23.4	18:29.9	6.47	0.3594
10	21:59.4	21:59.7	0.332	0.0001
11	21:59.7	21:59.8	0.023	0.0000
12	22:13.0	22:25.7	12.754	0.0039
Total			3291.011 ~ 55 Min.	100%

Global Statistics

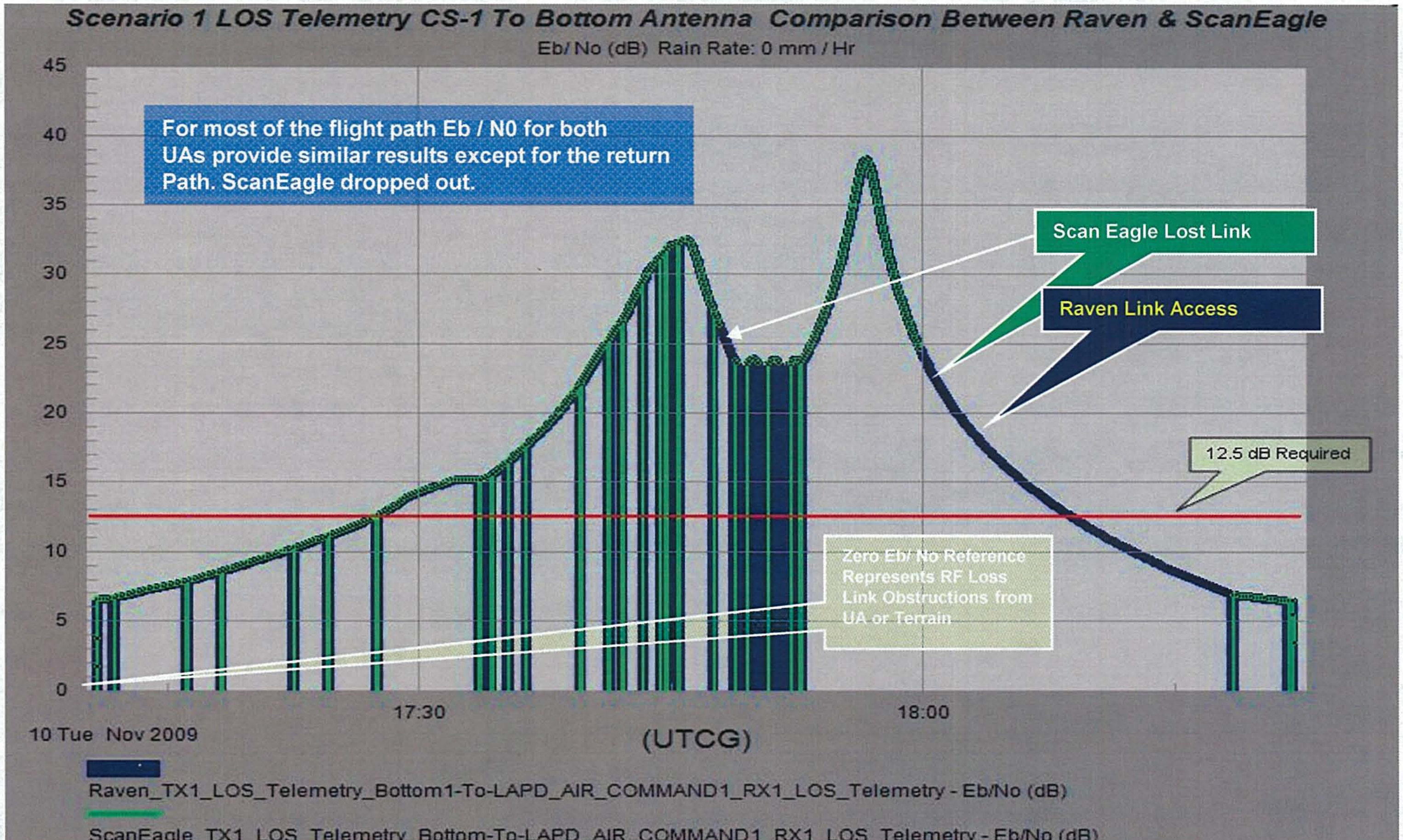
Reference	Quantity	Sub Total Gap Times
Gaps Greater Than or Equal to 3 sec	5	3451.751
Gaps Greater Than 2 sec & Less Than 3 sec	4	0.2909
Gaps Less Than or Equal to 2 sec	3	0.1173
Reference	**Gap**	**Gap Period (sec)**
Min Duration	11	0.023
Max Duration	8	3232.287
Mean Duration		274.251
Total Duration		3291.012

Example: GAP Period Statistics for Scenario 1 Raven LAPD Air Mobile Cruiser Transmitter TX1 To ScanEagle Receiver RX1 Top (LOS / Command)



	1	2	3	4	5	6	7	8	9	10	11	12
Duration (sec)	18.846	8.972	1.246	2.542	2.395	2.831	2.313	3232.3	6.47	0.332	0.023	12.754
Percentage (%)	0.0057	0.0027	0.0004	0.1412	0.0007	0.1573	0.1285	179.57	0.3594	0.0001	0.0000	0.0039

Example: Scenario 1 RF Telemetry Link Budget between CS-1 To Raven, and CS-1 ScanEagle



Eb/ No: The energy per bit to noise ratio (Eb/No) where Eb is the energy per bit and No = kT (Boltzmann's constant * system temperature).

Or, Is the measure of signal strength to noise ratio for a digital communication system at the input of a radio receiver provides the basic measurement. Depending on the modulation forms being used by the transmitter (MSK,PSK, BPKS, QPSK QPSK Quadrature phase shift keying), etc. will have different curves for bit error rate.

Summary

- This report is the end result of over a year of work done jointly between the FAA and NASA KSC.
- The work was done in support of the RTCA SC-203 Control and Communications Working Group.
- The use of QualNet was introduced due to a discussion during a RTCA SC-203 Control and Communications Working Group on the modeling and simulation being done for this report.
- It was found that when only a LOS link is used for a low elevation UA, at least three CSs are needed.
- LOS rain effects on the link were a concern on the longer traversed aircraft routes. As the UA traveled this route, the heavy rain rate of 90 mm/hr resulted in higher attenuation at 5.03 GHz. At one NM mile the rain attenuation was 2 dB, and at 25 NM the rain attenuation was 5 dB.
- For the BLOS links there were no dropouts on either the command or the telemetry links.
- Even at heavy rain rates the command link was above the 6.5 dB required for Scenario 5 and for Scenario 6. But, the telemetry link fell below the 6.5 dB required when rain attenuated the signal in Scenarios 5 and 6.

Summary

- With the proper use of modeling and simulation it is possible to analyze the effects of different requirements as well as the effects of natural requirements such as rain. This report addressed the availability of radio links for UAS as they fly in the NAS. This requirements development effort is a primary step needed to establish UAS standards permitting safe operations of UAS in the NAS.

Future Work

- Add more realistic antenna patterns, The report used a 3dB held hemispherical antenna top and bottom
- Add landlines for each scenario using Qualnet.
- Bring in real weather data as well as real time weather data.
- Look into the lower level communication items, like transmitters and receivers. This is possible if Matlab is added to STK.
- Model other links: ground crew, terminal
- Model BLOS with hand-off between satellites
- Need to model RF link between ATC and CS. Both Relay and Non-relay for nationwide (voice, data, video)
- Review other RTCA SC203 –CC architectures
- Study to Model Urban propagation in detail.

References

- *RTCA SC203 OSED Document 264 No.: 224-09/SC203-36S Version 11, Date: Oct 23, 2009*
- *RTCA SC203-CC005_UAS Control and Communications Architectures_vD_23Dec08*
- *RTCA SC203-CC016_UAS_CC_Availability_vF_13Dec10*